Ontario Geological Survey

Study 25

Results of SURTRACE Geochemical Surveys over the Marathon and Marshall Lake Areas

District of Thunder Bay

By

D.R. Clews and R.E. Lett

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FOREWORD

The test program of SURTRACE airborne geochemical sampling, described in this study, represents part of a continuing effort by the Ontario Geological Survey to support innovative developments in exploration technology suitable for Ontario conditions. The Barringer system is of particular interest because it combines the speed and flexibility of an airborne survey with the direct determining characteristics of geochemistry: the elemental composition of any target is revealed by the survey. Theoretically, therefore, it is suited to Ontario where problems of access in remote or difficult terrain are matched by the need to identify the areas of highest mineral potential within larger regions of favourable host rocks.

For many people, however, geochemistry has come to be regarded as a poor technique in Ontario where, largely because of complex overburden conditions, it often lacks the precise definition of targets provided by geophysical procedures. Nevertheless, geochemistry is seen as playing an increasing role in the evaluation and reevaluation of areas already surveyed geophysically. With an understanding of geochemical processes and an appreciation of overburden conditions, geochemistry can successfully identify the more favourable ground. Furthermore, geochemical dispersion often leads to the development of a characteristic pattern, or anomaly, in one or more elements that is much larger than the bedrock source. In addition, there are a number of forms of potentially economic mineralization (disseminated sulphide, high sphalerite ore, etc.), of which the main zone of Marshall Lake is an example, which have a more ambiguous response to airborne geophysical systems. Lack of definition is thus offset by the confident identification of a target area within which the more precise ground techniques can be applied with a very high chance of successfully locating mineralization.

E.G. Pye, *Director*
Ontario Geological Survey

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ABSTRACT

SURTRACE is a new technique which, despite some intensive research, is not yet fully understood. The sample medium employed, the particulate microlayer on vegetation (on leaves, needles, bark, etc.), is a complex product of the plants and trees themselves plus material which has settled out of the lower atmosphere following wind transport from elsewhere. Both organic and inorganic constituents are present which may or may not cause difficulties in the analytical technique employed. The processes by which materials are translocated from the soil, through the plant, and onto leaf and bark surfaces, are imperfectly known. Species variation, temporal changes and individual elemental phenomena may all contribute perturbations to the patterns recorded by SURTRACE. It is perhaps reasonable to consider the approach a modified biogeochemical procedure. As such, the reader should not expect element distribution patterns to be exactly comparable in terms of abundance and place to those revealed by soil or rock surveys.

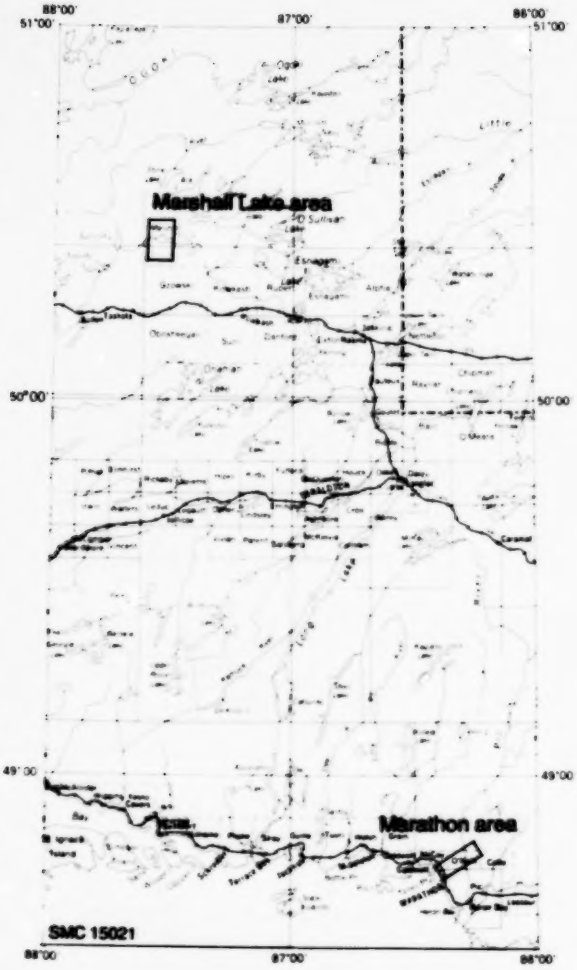
Despite these cautions, the strength and continuity of the responses found by SURTRACE at both the Marathon and Marshall Lake areas are impressive. Certainly SURTRACE is "seeing" the ground as evidenced by the strong positive correlation between Ca and Sr distribution patterns and the geology as mapped in the Marathon area. That the response in terms of absolute abundance is not exactly as found in the bedrock is reasonably attributed to the behaviour of these elements in the biological cycle. Other geochemical patterns can be related to known mineralization, other geological features, and to changes in the surface secondary environment, exactly the same controls which govern conventional geochemical surveys.

In considering this report and making any evaluation of the suitability and effectiveness of the SURTRACE system, the following points should be kept in mind:

(1) SURTRACE together with LASERTRACE are new instrumental techniques for use in exploration geochemistry which sample and analyse an as yet little known medium, the particulate material adhering to the surface of plants and vegetation. Empirical criteria for the identification and classification of geochemical patterns have been developed, but as yet, there is only limited practical experience in the field application of the system. Complete interpretation is not yet possible.

(2) SURTRACE, when applied over forested terrain, may be considered a modified form of biogeochemistry. It will not necessarily display element distribution patterns in exactly the same way as conventional soil geochemistry. Furthermore, since it is particulate material derived from the surface of the plant that is sampled, absolute abundance characteristics may differ from those displayed by whole plant samples (leaves, twigs), or soil organic matter (leaf litter).

(3) SURTRACE collects sample material continuously as it traverses over the vegetation. Each sample is thus a composite representative of 200-300 m of ground. These samples can be compared to channel samples in that the resulting analytical data for elements of interest is, in effect, an average over the distance sampled. Small, localized, very high concentrations of these elements — characteristic of anomalies related to narrow shear zones, mineralized horizons, or small bodies of mineralization — cannot be observed by SURTRACE. Broader



Location of survey areas, scale 1:2 000 000

areas of raised element values will be revealed where related to one or more narrow high order anomalies or a more extensive, but lower contrast, halo around the mineralization.

(4) The LASERTRACE analytical procedure is semiquantitative and cannot provide element distribution patterns in terms of absolute abundance. Further, as yet undefined, natural influences outside the instrumentation make direct comparison of raw analytical data from each survey flight impossible. This problem is largely overcome by the use of an empirically satisfactory procedure of normalization which permits comparison of variability of individual elements within and between flights. Patterns of element distribution are therefore more important than abundance. As a result, interpretation is essentially descriptive and qualitative.

(5) Finally, it should be remembered that the area covered by each SURTRACE survey is quite large. It is doubtful if similar areas of Ontario have ever been given geochemical coverage at a high sample density. When considering the character of the geochemical patterns revealed at this scale, a useful analogy may be to look at magnetic patterns shown by (a) ground readings on a grid over three or four claims and compare this with (b) high resolution airborne magnetics over a single township. Comparisons of scale and resolution are thought reasonable and appropriate.

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CONVERSION FROM SI TO IMPERIAL			CONVERSION FROM IMPERIAL TO SI		
SI Unit	*Multiplied by*	*Gives*	*Imperial Unit*	*Multiplied by*	*Gives*
			LENGTH		
1 mm	0.039 37	inches	1 inch	**25.4**	mm
1 cm	0.393 70	inches	1 inch	**2.54**	cm
1 m	3.280 84	feet	1 foot	**0.304 8**	m
1 m	0.049 709 7	chains	1 chain	20.116 8	m
1 km	0.621 371	miles (statute)	1 mile (statute)	**1.609 344**	km
			AREA		
1 cm^2	0.155 0	square inches	1 square inch	**6.451 6**	cm^2
1 m^2	10.763 9	square feet	1 square foot	**0.092 903 04**	m^2
1 km^2	0.386 10	square miles	1 square mile	2.589 988	km^2
1 ha	2.471 054	acres	1 acre	0.404 685 6	ha
			VOLUME		
1 cm^3	0.061 02	cubic inches	1 cubic inch	**16.387 064**	cm^3
1 m^3	35.314 7	cubic feet	1 cubic foot	0.028 316 85	m^3
1 m^3	1.308 0	cubic yards	1 cubic yard	0.764 555	m^3
			CAPACITY		
1 L	1.759 755	pints	1 pint	0.568 261	L
1 L	0.879 877	quarts	1 quart	1.136 522	L
1 L	0.219 969	gallons	1 gallon	**4.546 090**	L
			MASS		
1 g	0.035 273 96	ounces (avdp)	1 ounce (avdp)	28.349 523	g
1 g	0.032 150 75	ounces (troy)	1 ounce (troy)	**31.103 476 8**	g
1 kg	2.204 62	pounds (avdp)	1 pound (avdp)	**0.453 592 37**	kg
1 kg	0.001 102 3	tons (short)	1 ton (short)	**907.184 74**	kg
1 t	1.102 311	tons (short)	1 ton (short)	**0.907 184 74**	t
1 kg	0.000 984 21	tons (long)	1 ton (long)	**1016.046 908 8**	kg
1 t	0.984 206 5	tons (long)	1 ton (long)	**1.016 046 908 8**	t
			CONCENTRATION		
1 g/t	0.029 166 6	ounce (troy)/ ton (short)	1 ounce (troy)/ ton (short)	34.285 714 2	g/t
1 g/t	0.583 333 33	pennyweights/ ton (short)	1 pennyweight/ ton (short)	1.714 285 7	g/t

OTHER USEFUL CONVERSION FACTORS

1 ounce (troy)/ton (short)	20.0	pennyweights/ton (short)
1 pennyweight/ton (short)	0.05	ounce (troy)/ton (short)

NOTE–Conversion factors which are in bold type are exact. The conversion factors have been taken from or have been derived from factors given in the Metric Practice Guide for the Canadian Mining and Metallurgical Industries published by The Mining Association of Canada in co-operation with the Coal Association of Canada.

Results of SURTRACE Geochemical Surveys over the **Marathon and Marshall Lake Areas** District of Thunder Bay

by

D.R. Clews and R.E. Lett[1]

INTRODUCTION

During the period July 7th to 17th, 1979, an airborne geochemical survey was carried out on behalf of the Ontario Geological Survey by Barringer Research Limited, Rexdale. The principle objective of this survey was to assess the ability and efficiency of the Barringer SURTRACE® airborne geochemical system in the search for sulphide mineralization in the Precambrian Shield of Ontario. Two areas were selected with known base metal sulphide mineral occurrences where sufficient geological, geophysical and geochemical data were available to permit an evaluation of the survey results. The two test survey areas are located close to Marathon and south of Marshall Lake, Ontario (Figure 3).

In planning, conducting and appraising this test survey program, the Geophysics/Geochemistry Section of the Ontario Geological Survey and Barringer Research Limited received the generous support of other companies and individuals working in the survey areas. N.W.T. Copper Mines Limited and St. Joseph Explorations Limited are thanked for providing additional information from company files which aided evaluation of the Marshall Lake area. Mr. J. McDermott of N.W.T. Copper Mines Limited is thanked for his personal interest in the program and for permitting use of his camp on Marshall Lake as a temporary base for the field crew. S. Amukun and W.O. Mackasey of the Precambrian Section, Ontario Geological Survey provided geological support for the project. R. Sage of the Precambrian Section, Ontario Geological Survey and P.J. Whittaker of the Sudbury Regional Geologists Office, Ministry of Natural Resources, provided extensive geological support for the survey of the Marathon area.

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[1]Barringer Research Limited, 304 Carlingview Drive, Rexdale Ontario M9W 5G2. Manuscript approved by the Section Chief, Geophysics and Geochemistry Section, October 2, 1980. This report is published with the permission of E.G. Pye, Director, Ontario Geological Survey.

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Copies of all the analytical data obtained from this test program, together with maps showing the areal distribution of each element reliably reported in both survey areas are on file with the Geophysics/Geochemistry Section, Ontario Geological Survey, Ministry of Natural Resources, Queen's Park, Toronto.

This test survey program was funded by the Ontario Ministry of Northern Affairs.

At Marshall Lake, numerous copper-zinc sulphide occurrences are known and at one location a significant tonnage of mineralized material has been established. A total of 255 line-km were flown using the SURTRACE equipment installed in an Alouette II helicopter over an area 12 km by 18 km. In the Marathon area, copper-nickel sulphide mineralization is associated with gabbroic rocks close to the contact of the Coldwell intrusive complex and Archean metavolcanics. A total of 155 line-km were flown at Marathon over an area 8 km by 20 km.

The Barringer SURTRACE technique was originally designed for mineral exploration in desert and grassland areas. Previous surveys have established that the method can successfully locate mineralization in these environments. The present survey, using a modified system, represents the first application of airborne SURTRACE over northern forest. In addition to the different character of the sulphide mineralization, the two survey areas have contrasting relief and secondary environments, typical of conditions encountered during mineral exploration in the Canadian Shield.

Members of the airborne survey crew were: J. Keightley, Project Manager and Crew Chief; R. Regazzo, Operator; A. Tolley, Navigator; M. Herz, Data Technician. Laboratory analyses were performed under the direction of A.D. Murray and G. Stoute. Evaluation and interpretation of the airborne SURTRACE and ground geochemistry was carried out by D.R. Clews and R.E. Lett, geochemists who, together with J. Keightley, prepared this report.

Results of the survey indicate that major geological changes can be detected by the airborne SURTRACE data. In the Marathon area Ca, Sr and V were found to be consistantly higher over rocks of the Coldwell complex and the distribution of Ca clearly outlines a contact between the complex and older metavolcanics. The sporadic nature of trace element SURTRACE anomalies over mineral occurrences in both survey areas can be explained by the narrow exposure of the base metal sulphides and limited secondary dispersion of metals. Prominent multi-element anomalies do occur over sulphide mineralization where soil development is greater, promoting increased availability of elements to plants, and subsequent concentration in the vegetation microlayer.

THEORY OF SURTRACE

The earth's surface is covered with a microlayer of particulate material, in contact with the atmosphere, that is composed of organic and inorganic constituents. On exposed soils, the microlayer geochemistry has a relatively close relationship to that of the underlying parent materials. This relationship is demonstrated by results of microlayer sampling SURTRACE programs in arid regions where strong geochemical anomalies occur over known mineral occurrences ranging from porphyry copper to sandstone hosted uranium deposits

(Bradshaw and Thomson 1979). Studies have also shown that vegetation and the surface microlayer on vegetation may also be enriched in metals reflecting anomalous concentrations in overburden or bedrock beneath. The successful application of vegetation sampling to mineral exploration has long been known (Brooks 1972). More recently, research at Imperial College, London, has concentrated on the biogeochemistry of different plant species, including the distribution of metals in foliage and availability of metals at leaf surfaces. Much of the research has been directed into understanding release of metals into the atmosphere (Beauford *et al.* 1975).

Accumulation of elements on plant surfaces could involve absorption of elements through root systems from soil, or precipitation of particles from the atmosphere. Windborne particles may originate from industrial regions as atmospheric pollutants, or from soils and vegetation in rural areas. The larger particles in unpolluted areas are derived from local sources and their chemistry will reflect that of the near surface environment. Most terestrial plants will take up virtually any element from the soil on which they are growing regardless of whether it has a nutritional or nonfunctional purpose. Uptake of cadmium and zinc, for example, depends on the external concentration of the metal. Also, the form or availability of metals in the soil will be important in establishing the degree to which they will be absorbed by root systems. Once absorbed, the gross distribution of metals in plant tissue will depend on the behaviour of individual elements. Zinc and copper are relatively mobile and up to forty percent of zinc absorbed by plants will be translocated from the roots to shoots. Metals such as cadmium and lead, however, are largely retained by the roots. Different metals also have contrasting subcellular locations. Cadmium, for example, has an affinity for cell walls whereas zinc and copper are mainly associated with soluble components in the plant. Metals tend to accumulate in plant shoots and leaves, and, under certain conditions, will be released into the atmosphere (Turner 1969).

The transfer of elements into the atmosphere from vegetation is of special interest in relationship to surface microlayer and atmospheric geochemical methods in vegetated terrain. Movement of elements into the atmosphere from coniferous trees has been studied (Curtin *et al.* 1974) and it has been suggested that volatile exudates are the carriers. Recent work, however, using electron microscopy and weak chemical leaching agents has demonstrated that metals accumulate on stem and leaf surfaces in organic particulates. Research with radioactive (Zinc 65 and Lead 210) tracers in plant nutrients further indicates that metals are probably released into the atmosphere initially as submicron-sized particles (Beauford *et al.* 1975). Electrostatic attraction between these microscopic particles results in formation of larger agglomerates which become attached to plant surfaces.

The relationship between soil and particulate geochemistry is illustrated by results of a study made by Barringer Research over a small base metal sulphide occurrence in southern Ontario (Barringer 1979, 1975). Data for trace metals in soil, conifer samples, and particulates released from the conifer branches and leaves indicate that concentrations of many elements in the particulates are comparable to abundances of these elements in soil (Figure 1). In addition to geology, overburden character, and soil type, other factors which play a role in the degree of metal accumulation in vegetation particulates are plant species, climate, and the time of year when particulates are sampled.

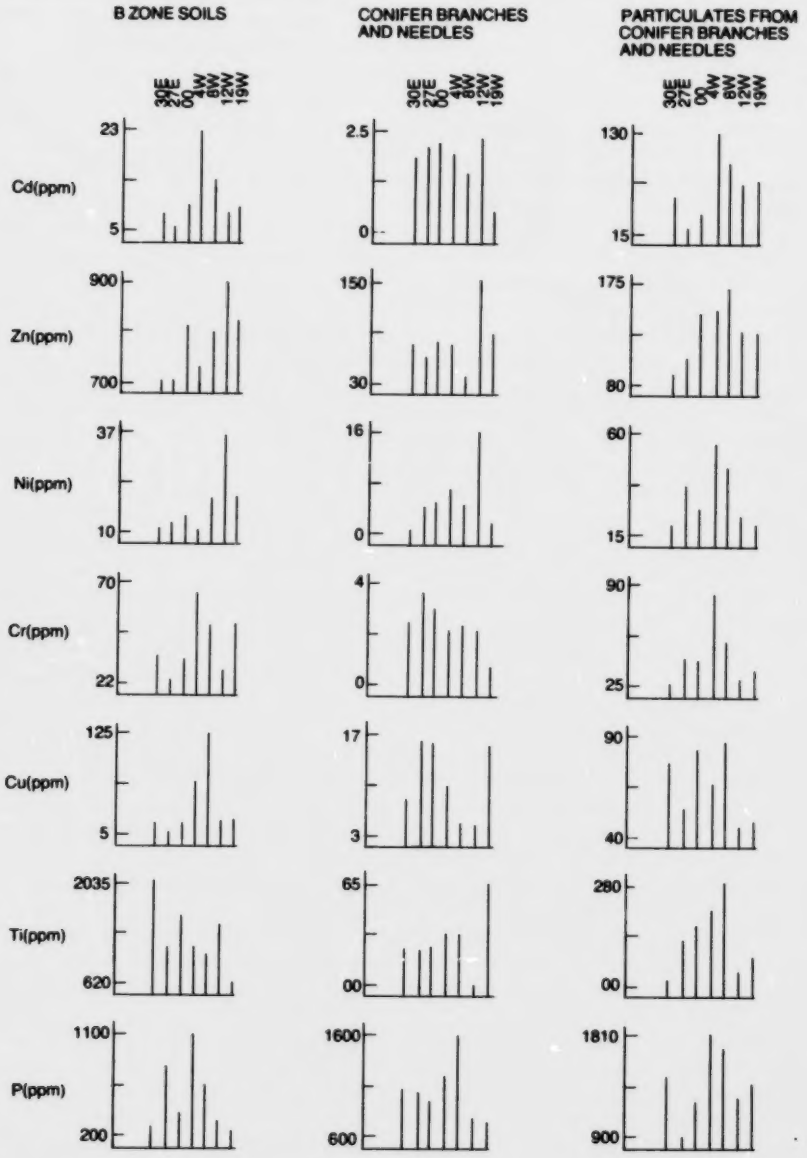
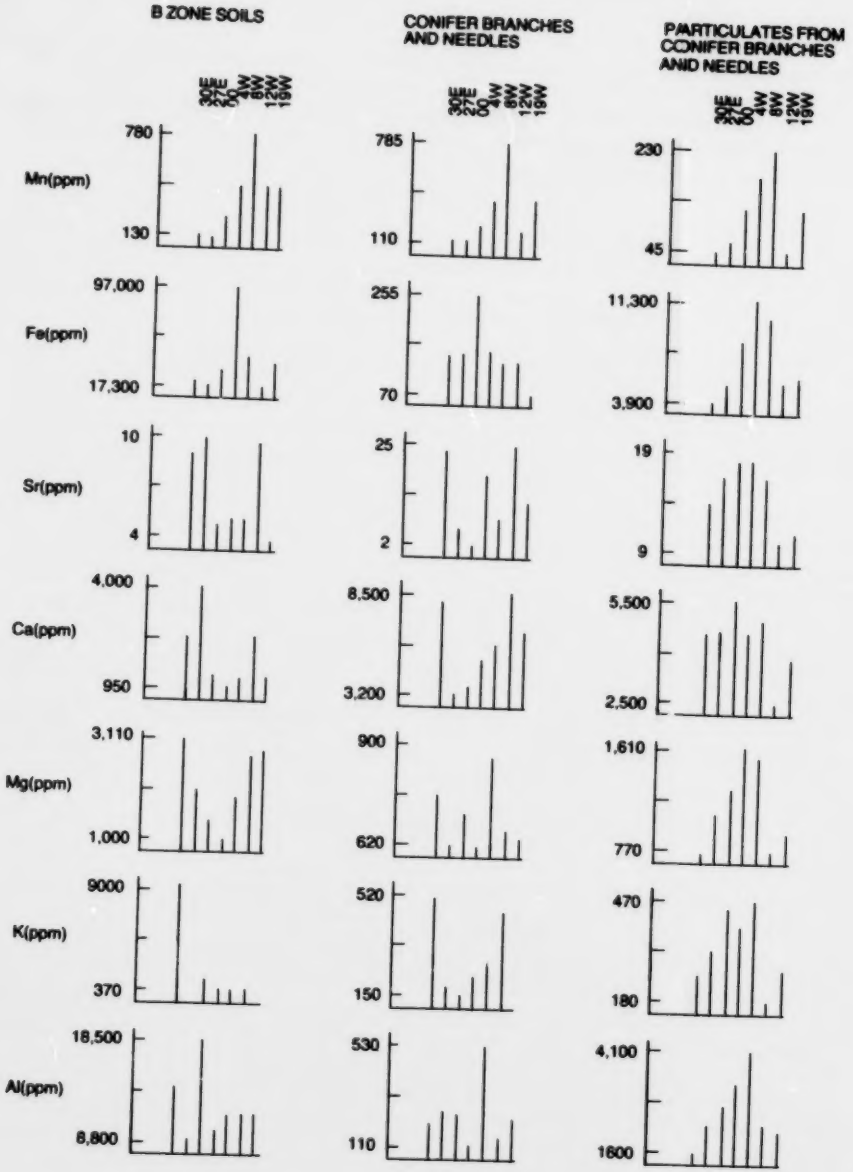


Figure 1—Concentration of elements in soils, plants and plant particulates over Zn mineralization extending from line 0.0 to line 12W, Deer Lake, Ontario.


B ZONE SOILS
CONIFER BRANCHES AND NEEDLES
PARTICULATES FROM CONIFER BRANCHES AND NEEDLES
Mn(ppm)
780
130
785
110
230
45
Fe(ppm)
97,000
17,300
255
70
11,300
3,900
Sr(ppm)
10
4
25
2
19
9
Ca(ppm)
4,000
950
8,500
3,200
5,500
2,500
Mg(ppm)
3,110
1,000
900
620
1,610
770
K(ppm)
9000
370
520
150
470
180
Al(ppm)
18,500
6,800
530
110
4,100
1600

Particulates are collected from the vegetation surface microlayer using the airborne SURTRACE sampling system described in the next section. This system is basically a sample probe attached to a helicopter which draws the probe tip over the vegetation surface. Vacuum equipment removes particles through the probe from the vegetation microlayer, sorts and cleans them in an inertial device, and impacts the material on high-purity adhesive tape. Samples are then analysed by the LASERTRACE system described in the section on "Analytical Techniques".

SURTRACE AIRBORNE SAMPLING EQUIPMENT

General

The SURTRACE technique has been developed for rapid, multiparameter exploration for both shallow and deep mineral deposits, geothermal regions, and hydrocarbon accumulations occurring in a wide range of environments. Airborne, vehicle-mounted, and man-portable versions of the equipment have been developed, giving the system a remarkable degree of flexibility in terms of high-speed coverage of terrain. Sampling speeds of up to 80 km per hour can be achieved in helicopter cross-country traversing, and speeds of 30 to 50 km per hour in vehicle traversing of section roads. The system operates in a newly recognized geochemical horizon — the surface microlayer — and has proven to have important application, not only in hard-rock exploration for minerals, but also for use in tracing the migration paths of solutions and volatiles in geothermal environments and sedimentary basins.

The SURTRACE technique and system concept has been conceived and entirely developed at Barringer Research Limited, and is protected in Canada by two currently pending patents.

History

AIRTRACE — The Fundamental Base for SURTRACE

The earth's lower atmosphere is characterized by a universal burden of suspended particulate material. Man-made pollution is a contributing source of material around cities and industrial areas, but in nonurban environments the giant-sized particulates (>10 microns or 10×10^{-6} m diameter) in the atmosphere are predominantly derived from the surface layer of soils and vegetation. In general, the larger and heavier the particles, the more local they are in origin. Under good atmospheric mixing conditions, there is a continual flux of particles lifted off the ground as well as a steady sedimentation and deposition of particles back onto the ground. Particles tend to be lifted by thermal plumes which constantly rise off the surface in response to solar radiant heating and achieve vertical velocities of several metres per second. These plumes contribute strongly to the familiar atmospheric turbulence that affects light aircraft flying at low altitude.

The AIRTRACE technique (a patented proprietary system of Barringer Research Limited) is based on this thermal plume activity and atmospheric mixing. The AIRTRACE equipment collects atmospheric particulates using either cyclones or louvred plate inertial devices (aerodynes). Thermal and particle flow rate sensors identify rising plumes and a fast switching technique separates the sample stream derived from these thermal plumes from particulates suspended in stagnant air. This provides an effective technique for selectively sampling the underlying terrain and minimizing dilution due to particles that have drifted from nearby or distant regions.

The AIRTRACE system has been mounted in both fixed-wing aircraft and helicopters which operate at survey altitudes that are normally less than 50 metres above the ground or vegetation surface. This low terrain clearance is used in order to optimize the collection of local particles in thermal plumes and minimize the effects of wind displacement. The incoming stream of particles is monitored by optical particle counters and collected on high purity adhesive tape. When operating over land the system functions best under sunny conditions when there is a slight wind. Radiant heating of the surface generates strong mixing activity, and such mixing is further accentuated by light winds. Strong winds can cause excessive smearing due to downwind displacement of particulate material and create difficult flying conditions.

Experience has shown that the AIRTRACE system described above can only work reliably in mineral exploration when the targets are large, or when regional phenomena are sought; and, when there are dry conditions and strong mixing in the lower atmosphere. This inability to reliably detect small mineral occurrences, and dependence on favourable weather conditions for successful airborne field operations were recognized as severe limitations for the AIRTRACE system. New objectives were established early in 1975 for development of a technique which would not be limited by such conditions. This became the basis for further research and development work which resulted in the present SURTRACE system.

SURTRACE Technique

The problems encountered with spatial resolution in the mining applications of the AIRTRACE system led to the development of ideas on the direct sampling of the surface microlayer from helicopters.

The primary objectives set for development of the SURTRACE system were as follows:

— The system should be capable of rapid, direct sampling of the soil surface microlayer from an airborne platform.
— The collected sample should be representative of the sampled area and it should be adequate for LASERTRACE analysis.
— The system should be capable of sizing the collected particulates for the purpose of assuring the localized character of the sample.
— There should be no smearing or contamination of the adjacent samples.
— The sampling probe should not constitute a hazard to the aircraft in flight or to people, animals and equipment on the ground.
— The sampling speed should be greater than 30 km per hour.

— The acquisition of suitable samples, and thus the survey productivity, should not be affected significantly by reasonable variations in local weather conditions.

Based on these objectives, various experimental systems were devised and tried. The initial effort concentrated mainly on development of an effective and safe sampling probe. Pneumatically damped inflatable booms were employed for their light weight, flexibility, low mass, low impact effect, and excellent capability to contour rough terrain. Such booms were constructed from light nylon fabrics and were deployed beneath the helicopter by means of air pressure generated by a high volume air pump on board the aircraft. A small sampling suction tube was contained within the inflatable boom. This type of probe was troubled by severe drag. At higher helicopter speeds the air drag forced the boom backwards and upwards, thus reducing helicopter ground clearance below the safe limit. The other major disadvantage of the boom was poor resistance to wear and tear.

The following generation of inflatable booms utilised an automatic deployment and retraction of either the whole probe, or just its lower part. This was aimed at minimizing the excessive wear and tear. The probe was deployed momentarily to contact the ground and was retracted immediately after a sufficient amount of sample was collected. During this initial development a standard AIRTRACE MK III tape deck (Figure 2) was used with only minor modifications to adapt it for SURTRACE application. A standard BCURA mini-cyclone was used in conjunction with the tape deck to unload the collected particulates from the relatively large volume of sampling air. This system configuration was troubled by severe particle hang-up problems, clogging, smearing between adjacent samples, and poor particle sizing. The results from a test survey were poor and overall progress was discouraging.

Shortly after the performance of the initial system was evaluated in early 1977, new concepts were established for the probe as well as the tape deck. A new dedicated SURTRACE tape deck was designed. The engineering effort was concentrated on solving the particle hang-up problems and particle sizing. The basic layout of the tape deck, tape driving mechanism and the tape itself remained the same as in the AIRTRACE deck. The optical counter was removed because it appeared to be a source of severe particle hang-up. A new type of filter was added to the sample input port to reject the very coarse particles and other large objects. A special two-way valve was developed which reversed the air flow in the suction tube in the probe after each sample was collected, and applied a burst of high pressure air to clean the tube of any residual particles. The vacuum gun for impaction of particles onto the adhesive on the tape remained basically the same as before.

Major effort, was concentrated on development of a highly efficient technique for removing the particles from the air stream and especially for separating the very fine particles from the coarse ones. Numerous devices were constructed and tested. As a result of this effort, a proprietary device called "Cyclone-Sieve" was developed. This device utilizes the air vortex generated in a cyclone, and a specially designed microsieve element for separating the fine and coarse particles in flight, before they are impacted onto the sampling tape. The size cut between the fine and coarse particles can be selected in steps between 20 and 150 microns.

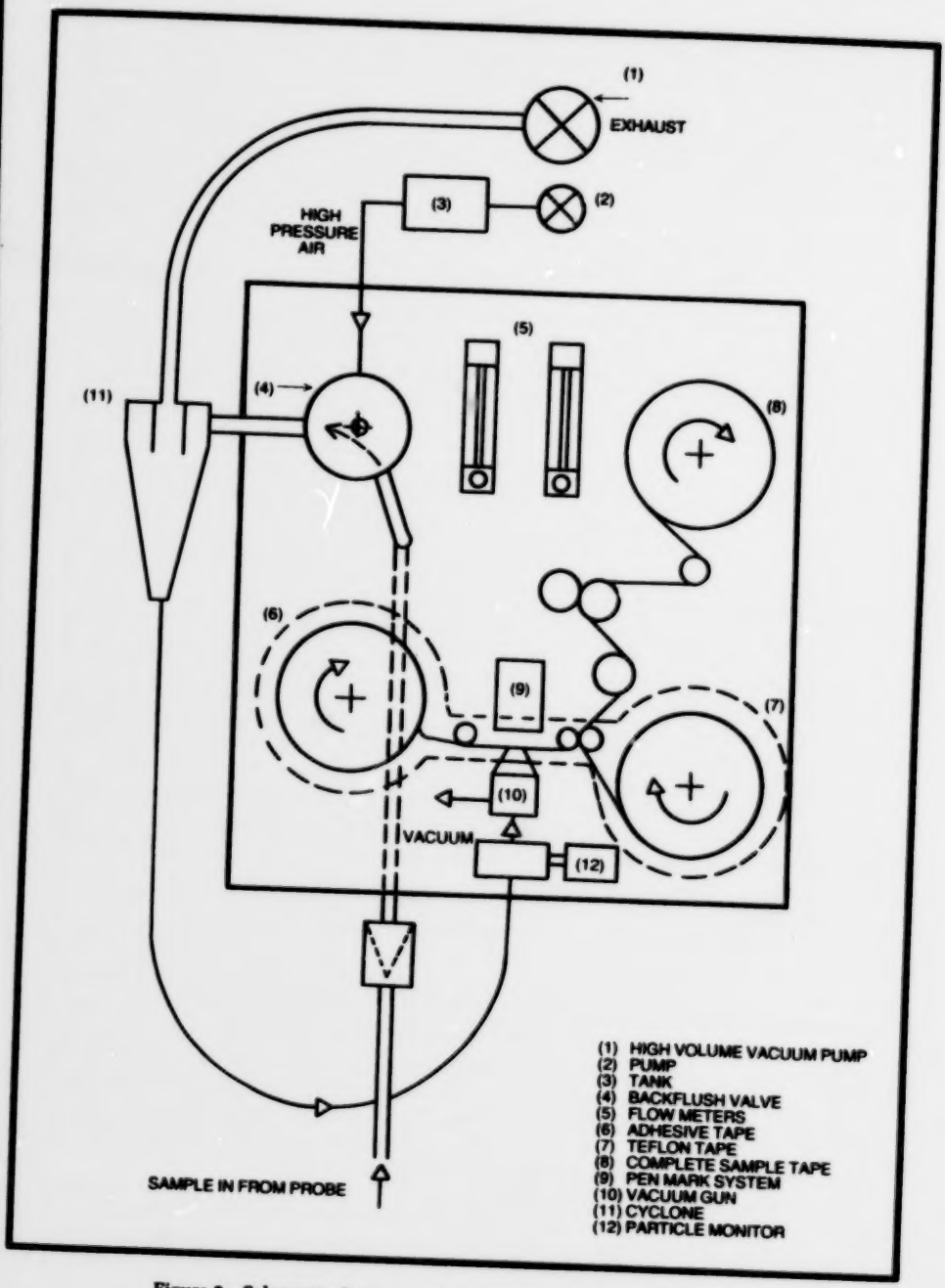


Figure 2—Schematic diagram of the MK III tape deck and accessories.

The other major engineering effort at this stage was concerned with the development of a new type of sampling probe. Test flights with the inflatable boom showed that a probe beneath the helicopter does not constitute any hazard to livestock or objects on the ground. Therefore, softness and low mass was no longer an important requirement for the probe. Engineering evaluation proved that a properly mounted pivoting, spring-loaded and damped "fishing rod" type fibreglass probe can follow the terrain features extremely well, and at the same time be far more wear and tear resistant than the inflatable boom. Several probes of this type were constructed and tested on various surveys, and were gradually developed into the current configuration which is now used on all surveys.

The operational experience with the MK III system from various field surveys showed that it would be possible to collect much larger amounts of sample than originally anticipated, even if the helicopter speed exceeds 50 km per hour. Collection of a larger sample would allow additional analyses, either conventional or nonconventional, or rerun of the LASERTRACE analysis several times for better statistical control of the data.

This concept was immediately accepted and new objectives were set in early 1978 for development of a MK IV tape deck which would be capable of reliably collecting and storing samples as large as 40 milligrams. The aim was to use such a system for hydrocarbon exploration where the LASERTRACE data need to be supplemented with analytical data on volatile compound tracers such as mercury, sulphur, iodine, and various hydrocarbon compounds.

The basic concept of the newly developed MK IV tape deck remained similar to the MK III version. All sampling and particulate sizing systems were identical. The major difference is in the actual sample tape assembly. The MK IV tape consists of three layers: a nylon filter tape, a thick rubber spacer tape, and the standard adhesive LASERTRACE tape. The spacer tape contains holes spaced closely to each other which, when covered by the filter tape from one side and the adhesive tape from the other, constitute discrete pockets (cells) in which the sample is deposited and stored. During the postflight analysis, the adhesive tape is stripped and analysed by LASERTRACE, and the residual sample in the cell is analysed by other techniques or covered again by a new adhesive tape for storage.

This system has been successfully used on production surveys in semiarid areas of the southwest United States and South Africa.

The Application of SURTRACE over Northern Forests

The idea of using the SURTRACE technique for sampling over heavily vegetated areas dates back to the very beginning of the SURTRACE concept. However, because of the tremendous engineering difficulties associated with this type of operation, the problem was not addressed until late 1978, when most of the fundamental SURTRACE problems were solved.

The major problem in this application was not the hang-up of the particles and their sizing, but rather their efficient and safe collection. The tape deck remained the same as for the surface collection, except for the addition of a highly efficient cyclone instead of the Cyclone-Sieve, and the reintroduction of the optical particle monitor.

The engineering effort was concentrated on the design of a suitable sampling probe which would collect the fine particles from the foliage of vegetation with high efficiency and which would, at the same time, ensure safe operation of the helicopter. This has been achieved by employing a similar type of fibreglass probe as before, except the end tip is now a larger diameter polycarbonate tube which has perforations for particulate entry. The lower portion of the probe is dragged continuously in the foliage and material is "vacuumed" off the surface of vegetation using a powerful suction pump.

Conclusions

The two airborne systems that have been outlined, AIRTRACE and SURTRACE, can be used for reconnaissance geochemical coverage of large or small areas where, for reasons of access or economics, it is better to explore initially with an airborne system rather than on the ground. The AIRTRACE system is suitable for regions where the weather is normally good and programs can be planned ahead with reasonable expectations for extended periods of sunshine, low winds and low rainfall.

The SURTRACE system can be used in place of the AIRTRACE system in regions where the weather is considered to be unsuitable for AIRTRACE, or where there are reasons for requiring high spatial resolution in the data. Alternatively, it can be operated as a follow-up tool for the AIRTRACE system by providing confirmation and detailed mapping of anomalies located with the AIRTRACE equipment.

System Description

The SURTRACE airborne sampling system developed by Barringer Research Limited is a novel technique for the collection of particulate material from ground surfaces.

These surfaces can be classed as either predominantly open, sparsely vegetated areas such as are found in semiarid regions, or densely vegetated regions common to such areas as Northern Ontario. Two types of SURTRACE systems have thus been developed to suit these contrasting environments.

The first surface is typified by the availability of large quantities of particulate material whereas the second presents the problem of collecting a representative sample from the small amounts of particulate material present on vegetation and foliage.

The basic arrangement of each system is the same, but they differ markedly in the quantity of sample collected and the manner in which it is actually collected.

The SURTRACE airborne sampling equipment, as applied to vegetation sampling and employed in the present surveys, utilizes a hollow suction probe mounted vertically below a low-flying helicopter to "vacuum" particles from the underlying vegetation and deliver these to a sample handling and storage system mounted within the aircraft. The particulate samples are secured on the collection tape by means of impaction onto the tape adhesive, and subsequently

sealed with an inert Teflon tape for further storage. A MK III tape deck advances this tape every few seconds. Built-in particle counters monitor the amount of material coming in and the collection is terminated and the tape is advanced automatically to the next discrete sample location when a preset particle count is reached.

Thus, the resulting sample tape takes the form of discrete spots (composed of approximately 200μg of material) located on the tape; each spot representing a short area of traversed terrain — typically 250 m.

The complete system is automatic in operation requiring the presence of an operator only to monitor the correct functioning of the equipment during flight, and for initial switch-on and set-up of various parts of the system prior to each survey flight.

The system is powered from the aircraft's 28 volt D.C. supply and utilizes advanced analog and digital electronic circuits to control the equipment operation, and D.C. pumps to provide the necessary air flows.

The normal three-men flight crew is made up of pilot, navigator and operator. The aircraft is flown with the lower 1.5-3.0 m of the 10 m long probe in contact with the vegetation at an average speed of 30-50 km per hour. Contact is audibly indicated to the pilot via a microphone sensor attached to the probe. Additionally, a mirror attached to the helicopter skids allows a visual indication of the probe position which is spring loaded into the vertical position.

A continuous strip 35 mm camera equipped with a wide-angle lens is used to photograph the ground continuously during the survey, and the navigator guides the pilot down survey lines which have been prelocated on aerial photographs. Navigation at this low altitude requires considerable skill.

Sampling Probe

The probe is approximately 10 m in length and consists of three tubular sections constructed of different materials — viz. an upper aluminum section, middle fibreglass composite, and lower high impact plastic tip.

The upper aluminum section provides the attachment to the support structure which is itself mounted on the aircraft frame. The probe assembly is pivoted at its upper end to allow motion along the aircraft longitudinal axis and is spring loaded down into the near vertical position by an extension spring. A hydraulic damper serves to control the motion of the assembly.

The probe assembly pivots back into a horizontal position to allow normal take-off and landing. Extensive operational experience with this probe arrangement has shown that no difficulty is experienced by pilots in adapting to operation with the probe, and no extraordinary flying techniques are required.

The middle section of the probe consists of a tapered fibreglass member which provides the required flexibility but also possesses sufficient strength to survive the occasional heavy impact with trees, etc.

The tip of the assembly is a 2.5 m section of thick wall polycarbonate tubing, with sample collection effected via a series of radial holes located in the forward portion of the tip's lowest 1 meter. The end of this tip is plugged with a removable "trap" that collects and holds the larger particles and vegetation debris that is collected by the probe but rejected by the filter at the entrance to the

tape deck. The whole tip assembly is quickly detachable for cleaning as required.

The middle fibreglass and upper aluminum section of the probe are lined with a nylon sample tube which is continuous through to the tape deck to minimize contamination and hang-up of the sample in this region. Additionally, during survey the probe flow is automatically reversed and flushed with high pressure air at the end of each sample period (5-10 secs) to minimize any possible contamination between adjacent samples.

As a safety precaution, the probe assembly is fitted with a shear pin at the upper end which breaks and releases the probe if a particularly hard impact with vegetation is experienced. To avoid lost survey time spent in recovering such a disengaged probe from what is often inaccessible terrain, a short safety line is rigged between the probe and aircraft cargo hook to maintain contact with the probe for subsequent reattachment at a regular landing site. Operational experience with this arrangement has shown it to be very effective, and it minimizes possible damage to probe or aircraft.

Tape Deck

A schematic block diagram of the MK III deck and accessories is shown in Figure 2 and its operation can be described as follows. The stream of particulate laden air from the sampling probe passes up through the filter, which rejects particles coarser than 200 microns in diameter, and then through the backflush valve (4) to the cyclone (11). The cyclone, driven by the high volume vacuum pump (1), is an inertial separation device — particles below about 1 micron diameter are carried up and out through the top exit, whereas the coarser particles are collected out of the bottom of the cyclone and passed at high speed to the particle monitor (12).

The backflush valve presents a smooth unrestricted flow path to the air in both of two possible positions and is used to duct high pressure clean air to the probe at the end of each sampling period. At the same time, it also closes the entrance to the cyclone momentarily to effect cleaning of the latter by the high volume vacuum pump.

The particle monitor is an electro-optical device that measures the light scattered from the particles as they pass through an illuminated region within the monitor. The scattered light signal, which is related to the mass of particles present, is accumulated electronically and, on reaching a preset threshold, automatically initiates the advancement of the tape, back flush cycle, and new sampling period.

The particles are impacted onto the adhesive tape (6) (sticky side down) by the vacuum gun (10) which utilises the momentum of the fast-moving particles to carry them onto the adhesive, while spilling the air-carrier flow to exhaust via the vacuum pump.

As each sample spot is created on the tape, its position is marked by the pen mark system (9), which serves as a register for the next sample spot, and it is then covered by a Teflon cover tape (7) to protect it.

All the drive motors and valve arrangments for the deck operation are contained on the rear, while the electronics associated with its operation are located in a console adjacent to it.

Installation

The complete survey system is designed specifically for airborne use and comprises lightweight subsystems that are easily fitted to helicopter airframes and well able to operate in the high levels of vibration, shock, and extremes of temperature often encountered.

The tape deck and associated electronic equipment are mounted internally, while the boom support structure, flight path camera, and pumps are mounted externally, usually on existing cargo support structures.

Installation of a survey package can be accomplished by trained personnel in one to two days and usually little or no modification of the aircraft is required.

Survey Technique

Standard airborne survey techniques are used — parallel flight lines being spaced at intervals determined by the resolution required and typically 4-5 samples per line-kilometer are collected. As mentioned above, navigation at the low flying altitude is difficult because of the low horizon, but this is offset partly by the slow flying speed allowing appreciable time for course corrections.

Flight path recovery is accomplished by comparing the exposed film from the 35 mm camera with the aerial photos and by the aid of notes and annotations made by the navigator. For correlation between the flight path position and sample number, a real-time clock in the electronic equipment generates sequential fiducial numbers that are exposed at regular intervals on the film and also marked on a strip-chart recorder in the equipment console. Sample numbers are also marked on this chart and the sample tape, allowing later recovery of each sample position on the aerial photos. Subsequent data reduction generates map overlays of each sample position and survey parameter of interest — e.g. copper concentration.

Individual flight times on the order of two hours are usual because of the limited helicopter fuel capacity, but it is possible to accomplish 6-8 hours of survey flying per day. Typically, survey areas are some distance from commercial air fields, and thus it is usual to have a local fuel cache or fuel supply truck near the survey area to minimize aircraft ferry times.

Because of the nature of the survey technique, bad weather has a significant influence on the time available for surveying. Obviously the technique is not applicable during and immediately after heavy rainfall, but experience has shown that after a drying period of approximately 1/2 day, adequate sample can be collected from coniferous vegetation. An advantage is that collection is from the highest, and therefore quickest drying, parts of the tree cover.

Also, because of the low flying altitude, any appreciable wind can produce unsafe flying conditions, and, even in moderate winds, flying up-wind is a decided advantage. However, experience gained in Northern Ontario during a particularly wet July period has shown that helicopter down-time due to bad weather did not exceed 20% of the total.

ANALYTICAL TECHNIQUES

Introduction

Samples collected by the SURTRACE system were analysed for twenty five (25) elements using the LASERTRACE system. The elements monitored by the system are: C,Al,Ca,Cu,Cr,Co,Fe,Pb,Mg,Mn,Mo,Ni,Ag,Be,Sr,Ba,Zn,Cd,Na,Si, P,Th,Ti,V,and K.

The Lasertrace Analytical System

System Description

The LASERTRACE analytical system utilizes a direct reading multi-element RF argon plasma emission spectrometer, ARL Model QA-137. This system is covered by Canadian patent application.

Samples of particulate material are analysed on the survey tapes for their element composition by direct solid sample pyrolysis and vaporization using a high-energy pulsed CO_2 TEA (carbon dioxide transversally excited at atmospheric pressure) laser. A laser plume is created above the sample and this plume is carried into the plasma by an argon gas flow. Light emissions of specific wavelengths, characteristic of the elements listed above, are monitored. The signal output in millivolts is relayed to a 9821 Hewlett-Packard calculator where data are stored on magnetic tape for further data processing.

The analytical signal resulting from solid sample analysis by laser pyrolysis has a unique characteristic in that a very large proportion of the sample enters the plasma over a short time span. As a result, the signal is enchanced over the background noise, and detection limits are greatly improved. The technique is ideal for the analysis of submilligram amounts of sample which are typical of SURTRACE samples. The LASERTRACE system, calibration and standardization procedures, and comparison of LASERTRACE with atomic absorption and conventional plasma spectroscopy data is described in detail by Abercrombie *et al.* (1978).

LASERTRACE Data

The millivolt readings from LASERTRACE analysis are recorded initially on one-eighth inch (1/8") magnetic tape and ultimately transferred to 9-track half-inch magnetic tape where sample numbers are replaced by the corrected fiducial numbers. In many of the previous SURTRACE surveys carried out by Barringer Magenta Limited, millivolt readings are converted into a semiquantitative estimate of element abundance known as "LASERTRACE or pseudo ppm". The

theoretical concept is based upon estimation of the total mass of material that has entered the plasma. Since the SURTRACE system collects large particulates (50 microns or greater) the laser is incapable of complete volatilization of the sample and consequently the mass of material entering the plasma is unknown. However, all the major elements (including carbon) and a large percentage of minor elements are analysed. The mass of each of these elements in the sample can be determined and their concentration as "LASERTRACE ppm" may be calculated by assuming that the oxides of the elements represent 95% of the mass of material entering the plasma.

For the present surveys, raw millivolt (mv) readings have been used as a measurement of element abundances because the sample composition was found to be incompatible with the mathematical algorithm normally employed to compute "LASERTRACE ppm".

The first stage of the procedure normally used to derive "LASERTRACE ppm" is to calculate a series of ratios (D_j) for the mv reading of each element over the mv reading for Si. A second set of ratios (R_j) are also computed for element concentrations in calibration standards over known Si values. Total element abundances in each sample relative to Si can be calculated from the product $D_j.R_j$. Major and minor oxides (e.g. SiO_2,Fe_2O_3,CaO,CuO) are assumed to constitute 95% of the total sample mass and "LASERTRACE ppm" values can be calculated from the expression:

$$\text{LASERTRACE ppm} = \frac{T_j \times 10^{-6.95}}{T_{(TOT)}} \times \frac{95}{100}$$

where $T_{(TOT)}$ is the total of all element abundances calculated from the oxides using stoichiometric conversion factors. Consequently, "LASERTRACE ppm" values are representative of element abundances providing the oxides constitute the bulk of the samples.

This assumption is valid for samples collected in arid regions where the material is predominantly inorganic, but may not be true for highly organic samples typical of the vegetation surface microlayer because carbon containing organic compounds cannot be adequately represented in the algorithm. "LASERTRACE ppm" values for vegetation SURTRACE samples may reflect variations of organic carbon rather than actual element abundances. Interferences are also possible due to vapourization of carbon from the adhesive tape during laser pyrolysis.

The sampling system ensures uniform quantity and uniform distribution of particles on the tape. The laser energy is fixed and thus a uniform quantity of material is vapourized by the laser pyrolysis. In vegetated areas, millivolt values are therefore considered to be more representative of element abundance and can be used to demonstrate variability or contrast between samples.

Standards and Analytical Precision

Normally the LASERTRACE system is calibrated by geochemical standards of known composition available from the United States Geological Survey. Soil standards U.S.G.S. #6 and #2 are used for instrument calibration and quality

control monitoring respectively throughout the analysis. These standards are prepared in a manner similar to that of typical survey samples and are inserted into the survey tapes at regular intervals (every 150 samples). In the daily operation, the instrument is calibrated at the beginning of the day with U.S.G.S. soil standard #6, and the performance is monitored throughout the day with standard #2. Plasma blanks are recorded every 20 samples to eliminate the effect of instrumental drift.

The behaviour of standards was monitored continuously during the two-day period in which the SURTRACE samples were analysed. At present, a computer program capable of summarizing all the standards and calculating analytical precision is not available. However, precision was calculated from standards monitored during analysis of five flights and is tabulated in Table 1. In general, those elements with extremely poor precision (Co,Ag,Cd,Th) are present in concentrations close to or below the detection limit of the system, and subject to considerable noise problems during analysis. This is described in greater detail in the following section.

TABLE 1- ANALYTICAL PRECISION FOR ELEMENTS DETERMINED BY LASER-TRACE BASED ON TWENTY FIVE RE-ANALYSES OF U.S.G.S. STANDARD # 6. PRECISION IS IN PERCENT OF THE 95% CONFIDENCE LEVEL.

Element	Percent Precision	Element	Precision Percent
Al	17.2	Be	21.0
Ca	50.3	Sr	18.9
Cu	33.3	Ba	11.8
Cr	11.0	Zn	23.0
Co	76.6	Cd	80.3
Fe	28.7	Na	50.5
Pb	15.2	Si	21.6
Mg	29.0	P	19.1
Mn	16.1	Th	343.6
Mo	31.4	Ti	10.1
Ni	26.8	V	19.0
Ag	86.1	K	16.1

Detection Limit

Because the samples are too small to be weighed, the determination of detection limits for elements in SURTRACE samples can only be quoted for normally encountered sample weights.

By experiment, it is possible to determine the relationship between the response of the spectrometer (in millivolts) and the mass of an element (in ng) in the plasma. Noise levels of the analytical system are determined by examination of the recorded plasma blanks after every 20th sample. From an examination of blank to signal ratio (in millivolts) it is possible to classify the elements into two groups. In general, those elements with a sample signal to blank signal ratio greater than 10 are not affected by instrument noise and the analytical data can be used with confidence. However, elements with a ratio much less than 10, i.e. the sample response is close to that of the blank, must be considered as of doubtful value. The two groups of elements are listed in Table 2.

TABLE 2- RELATIVE CONFIDENCE OF ELEMENT ANALYSIS DETERMINED BY LASERTRACE

Elements With Signal to Blank Ratio Greater than 10:1	Elements With Signal to Blank Ratio Less than 10:1
Al, Ca, Cu, Cr, Fe, Mg, Mn, Ni, Sr, Ba, Zn, V, Na, Si, P, Ti, K	Co, Pb, Mo, Ag, Cd, Th

Analysis of Forest Litter Samples

The forest litter samples from the present surveys were digested in a hot nitric-perchloric acid mixture and analysed for trace and minor elements by plasma emission spectroscopy. An aliquot of the milled litter sample was digested for 12 hours in a 4:1 v/v mixture of concentrated perchloric-nitric acids until a clear solution was obtained. Solutions were diluted and aspired directly into the RF argon plasma emission spectrometer, previously calibrated using standards. Using this procedure, Ag,Ca,Co,Cr,Mo,Ni,Zr,Pb,Si,Sr,Ti,V,Zn,Th, Sn,Fe,K,Mg,Mn,Na, and P in ppm were determined simultaneously in the samples.

Vegetation Leachates

Roughly 10 g of dried vegetation shoots (mainly pine needles) were leached with a one percent solution of dilute nitric acid for 12 hours. The leachates were analysed for Pb,Si,Sr,Ti,V,Zn,Th,Sn,Ag,Cd,Co,Cr,Hg,Ni,Zr,Al,B,Ba,Be,Ca,Cu, Fe,K,Mg,Mn,Na, and P by plasma emission.

Data Reduction and Presentation of Results

Introduction

The data reduction process commenced in the field where all records and tapes were inspected and the appropriate annotation of records and data listings prepared. Initial flight path recovery was completed in the field, then checked and modified where necessary in the office. Following acceptance of flight path recoveries, the flight path maps of both surveys were digitized and referenced to an arbitrary origin. The coordinates of the recovered and accepted fiducials were stored on computer compatible half-inch magnetic tape. SURTRACE sample locations are plotted at the fiducials of the centre of the sampling period.

Optimum interpretation of SURTRACE data is dependent on correct estimation and allowance for the factors of variable sample loading and variable meteorological conditions between flights. The techniques used to best compensate for these variables were developed after considerable research and orientation studies conducted largely on an experimental basis.

A flight is a series of lines flown continuously without the aircraft landing. Despite rigorous quality control of the raw data, differences in element values occur within and between flights, and are believed to reflect temporal and areal variation of the moisture content in the surface microlayer. Accordingly, a normalization procedure has been developed to minimize these differences.

Normalization of Data

The first step in the normalization process is the determination of the mean (μ) and the standard deviation (σ) for each element within each flight. The computation is an iterative process. In the first instance all millivolt values are used to compute μ and σ. In the second iteration all values greater than $\mu + 2\sigma$ are rejected and a new μ and σ are computed. The iteration is continued until the difference between successive means (μ) is less than 10-5μ or ten iterations, whichever comes first.

$$Z_{ij} = \frac{x_{ij} - \mu_j}{\sigma_j}$$

where

Z_{ij} = The normalized value of sample i, element j
x_{ij} = The millivolt value of sample i, element j
μ_j = Mean of element j (based on the algorithm)
σ_j = Standard deviation of element j (based on the algorithm).

Normalized values for each flight represent a population with zero mean and a standard deviation of one. The normalized data for flights can thus be realistically compared since each will have identical mean and standard deviations to compute final normalized millivolt values. By adopting this procedure, a dimensionless scale is produced which obviates the need for absolute abundances, yet retains all the variability of the data; direct comparisons can thus be made within and between flights.

Symbols from "•" to "$" representing mean plus integer standard deviation intervals (e.g. 0.5,1.5,2.5) are specified in the line-printer map plotting routine. The normalized millivolt data for each element are classified according to standard deviation intervals, merged with coordinates for sample locations, and plotted on line-printer maps.

Data Listings and Line-Printer Maps[1]

Data listings and basic statistical parameters were prepared by computer. Data listings are presented separately. Printer maps were generated on the line-printer for each monitored element. Contoured maps were prepared from the original line-printer maps for four of the elements selected after consultation with the Ontario Geological Survey.

On the line-printer maps each sample point is represented by a single symbol (• to $). Thus, a dot represents all samples which have normalized values less than $\mu + 0.5\sigma$; 1 represents $\mu + (0.5 \text{ to } 1.5)\sigma$; 2 represents $\mu + (1.5 \text{ to } 2.5)\sigma$; etc.; to 9 which represents $\mu + (9.0 \text{ to } 9.5)\sigma$; with everything greater than $\mu + 9.5\ \sigma$ being represented by a $ sign.

The printer maps were produced rapidly and allowed an initial evaluation of the distribution of the elements. The maps were used in the preliminary interpretation of SURTRACE data, although the accuracy of the location of any one point is limited by the resolution of the line-printer. Copies of these line-printer maps were submitted to the Ontario Geological Survey prior to the final presentation.

Product and Smoothed Data Maps

In addition to basic line-printer maps for normalized millivolt data in terms of standard deviations, element product and smoothed averaging procedures were applied. Element products, for example Cu.Ni, can be useful for interpretation because the product values tend to enhance significant element association and at the same time suppress spurious variations. Product maps were prepared from the raw millivolt values for Cu.Ni in SURTRACE samples over the Marathon area and for Cu.Zn over the Marshall Lake area. Values are presented as standard deviations in the same manner as the basic line-printer maps. Smoothing of the data was attempted using an averaging technique. Basically, the average of all sample points was calculated within a circle of uniform radius providing that the number of points within the circle exceeded six. The area of the circle was chosen to include a minimum of two flight lines. Smoothing was performed on Ca,Sr and Cu over the Marathon area; Cu,Zn and Ca over the Marshall Lake area. Average values are presented as standard deviation units.

[1]On file with the Geophysics/Geochemistry Section, Ontario Geological Survey, Ministry of Natural Resources, Queen's Park, Toronto.

SUMMARY OF FIELD WORK

General Statement

The field program was designed to be relatively flexible in view of the necessity for dry conditions during sampling and the unpredictable weather typical of the north shore of Lake Superior. Originally, a base for airborne operations was planned at Geraldton roughly midway between the two survey areas. This base would have avoided major relocation of the ground support in the event that one of the areas was inaccessible due to bad weather. However, a stable weather system prevailed over the region during early July, 1979, and it was decided to survey the Marathon area from a base close to Marathon village rather than from Geraldton. Considerable ferry time was therefore saved. After completing the survey of the Marathon area, the crew relocated to Nakina north of Geraldton, a base from which the Marshall Lake area was surveyed.

Marathon Area

Marathon is located on the north shore of Lake Superior roughly 250 km east of Thunder Bay (Figure 3). The economy of the community is largely based on a pulp mill and logging industry. Services available in Marathon include hospital, stores, several motels, and an uncontrolled airstrip. The village is linked to the Trans Canada Highway 17 by a paved road and is also served by the Canadian Pacific Railway.

An operations base for both airborne and ground sampling surveys was established at the Travellers Inn, located on the Trans Canada Highway roughly 3 km west of the secondary road to Marathon. This base was also situated on the southern end of the actual survey area. Fuel for the Alouette II helicopter was provided by a cache set up by the Ontario Ministry of Natural Resources on the Marathon airstrip.

The field crew mobilized from Toronto on July 7th, arrived at Marathon the same day and commenced airborne sampling on July 8th. A total of 150 line-km of survey work was completed by July 10th when heavy fog during the afternoon of that day terminated operations and delayed relocation to Nakina. A light drizzle or mist was common until about 10 00 hours every morning due to the proximity of Lake Superior. However, it was found that this had no detrimental effect on sample collecting efficiency providing that the sun had been on the trees for approximately one hour before collection was attempted.

Airborne SURTRACE sampling was carried out along flight lines oriented N60E, approximately 10 or 18 km long and 200 m apart. Wherever possible, a collection rate of 3 to 5 samples per km was maintained throughout the survey. A summary of the number of survey lines per day, number of hours engaged in sampling and other relevant logistical data is given in Table 3.

During the period of the airborne SURTRACE survey, a ground crew collected forest litter and vegetation samples along a single traverse orientated parallel to the flight lines and crossing the main mineralized zone in the centre of the survey area. Forest litter samples were collected at stations 50 and 100 m

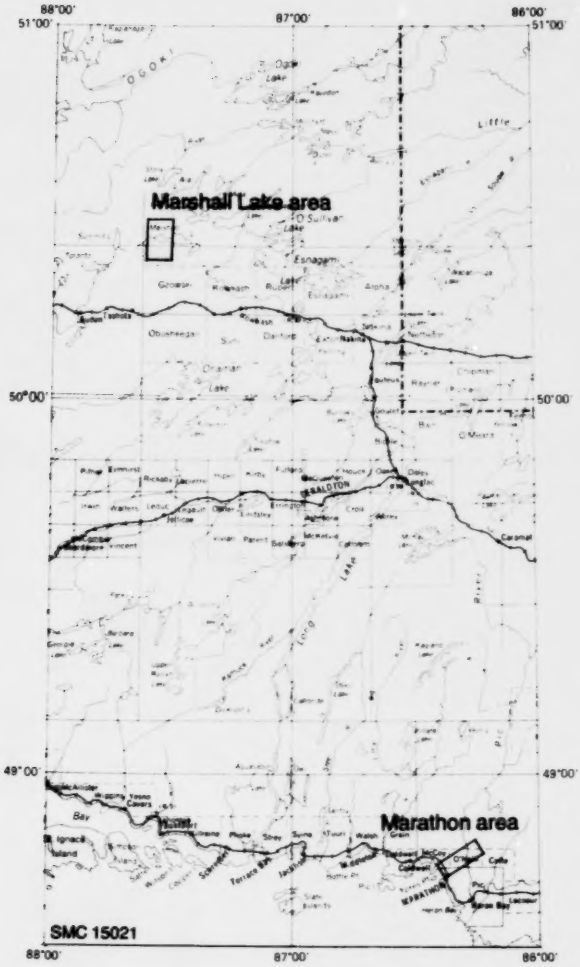


Figure 3—Location of survey areas, scale 1:2 000 000

TABLE 3 SUMMARY OF AIRBORNE SURTRACE SURVEY LOGISTICS

1. Marathon Area

Date	Total Survey Hours	Hours in Sampling (on line)	No. Line-Kilometers Sampled
July 8	2.75	0.6	15
July 9	4.9	2.4	100
July 10	2.9	1.4	55
TOTAL	10.55	4.4	170

Total Fuel Consumed	440 gallons
Total Helicopter Hours (including ferry time)	12.3
Consumption per Hour	36 gallons
Line-Kilometers Sampled per Hour	38

2. Marshall Lake Area

Date	Total Survey Hours	Hours in Sampling (on line)	No. Line-Kilomters Sampled
July 11	2.5	1.6	60
July 12	1.1	0.6	20
July 13			
July 15		Aircraft Disabled - Bad Weather	
July 16	5.5	2.9	70
July 17	5.6	4.1	100
TOTAL	14.7	9.2	250

Total Fuel Consumed	898 gallons
Total Helicopter Hours (including ferry time)	25.7
Consumption per Hour	35 gallons
Line-Kilometers Sampled per Hour	27.2

apart. Vegetation samples were collected continuously between these stations. Access to the traverse, which extended for 8 km north and south along the Pic River, was along a gravel road from the Highway, by helicopter, and by canoe along the Pic River.

Marshall Lake Area

The operations base for the Marshall Lake area SURTRACE survey was established at Shores Motel, Nakina. This community is located 60 km north of Geraldton along a secondary paved highway which joins Highway 11 just south of Geraldton. Although Marshall Lake can only be reached from Nakina by a winter road, a gravel logging road passes roughly 20 km east of the survey area. A support vehicle for system repairs and a small fuel cache were stationed on this road during the survey.

Services provided in Nakina include stores, Canadian National rail depot, fixed-wing float plane base, airstrip, and bulk fuel supplies located on the airstrip. The latter enabled refuelling of the helicopter before daily operations. Fuel was also provided by a cache positioned by the Ministry of Natural Resources at a fishing camp at the western end of Marshall Lake.

Airborne sampling commenced on July 11th and was completed by July 17th. A total of 255 line-km were sampled along north-south orientated lines with a basic line separation of 200 m and 400 m, and line lengths of 10 km and 5 km. Three days were lost during the Marshall Lake survey due to helicopter mechanical problems, high winds and rain. Data summarizing daily production and total flying are given in Table 3.

Ground sampling was carried out during the same period from a base camp at the west end of Marshall Lake. Forest litter and vegetation samples were collected along two traverses 6 km long and 500 m apart, with sampling intervals ranging from 50 to 100 m. Samples of new growth from both evergreen and deciduous trees were collected continuously along the traverse.

TOPOGRAPHY, OVERBURDEN, VEGETATION, AND GEOLOGY

Introduction

The two survey areas have contrasting topography, geology and type of sulphide mineral deposit. Rugged topography and high relief, typical of the north shore of Lake Superior, is present throughout the Marathon area. Here, copper-nickel sulphides occur in gabbroic rocks of the Coldwell complex along a contact with Archean metavolcanics. The Marshall Lake area is one of low relief in which Archean rocks hosting several significant copper-lead-zinc sulphide occurrences are partially concealed beneath a cover of glacial deposits.

Marathon Area

Principal topographic features of the survey area are the south flowing Pic River, extremely rugged terrain to the southwest of the river, and a gently sloping land surface northeast of the river. Hills generally have gently dipping north-facing slopes, rounded tops and very steep, often precipitous, south facing slopes. This morphology reflects erosion due to Pleistocene ice advance from the northeast. The area is dissected by several major valleys including the Pic River valley, northeast-trending depressions occupied by Hare and Bamoose Lakes, and a prominent group of parallel, northwest-trending, steep-sided valleys in the southern part of the survey area. Outcrop is frequently exposed in the bottom of the smaller valleys or they contain a thin fill of sandy clay. Where free drainage through the valleys is impeded, local swamps have developed.

Up to 30 m of calcareous varved clay and overlying gravels have been deposited in the Pic River valley during periods of recurrent deglaciation. The fluvioglacial and lacustrine materials extend a considerable distance along the course of the river and are up to 4 km wide in the survey area. Except for the northeast edge of the area, bedrock on the east side of the river is almost completely concealed beneath the surficial material. The clays and gravel form a gently sloping land surface dissected by small, steep-sided, meandering valleys in which flow active tributaries to the Pic River.

Soils formed on areas of high relief are typically immature where bedrock is exposed, or are represented by podzols or brunisols where there is a greater accumulation of surficial deposit. The soil and overburden support a mature growth of jack pine, white pine, red pine, eastern hemlock, yellow birch, and maple. On the varved clay, particularly east of the river, the forest growth is more deciduous in character consisting of yellow birch and poplar mixed with jack pine. A dense undergrowth of alder, maple saplings and other shrubs is ubiquitous throughout the region.

The geology of the survey area has been described by Puskas (1967) and Whittaker (1976) and is summarized in Chart A. In the southern and central parts of the area, gabbroic and syenitic rocks of the Coldwell complex are intruded into older Archean volcanic rocks which form the western end of the Wawa Structural Subprovince. Archean felsic volcanic rocks, largely concealed beneath fluvioglacial deposits, are dominantly grey coloured, massive, fine-grained rhyolite agglomerate. Close to the contact of the Coldwell alkalic complex, the volcanic rocks are coarser textured and locally bleached reflecting the effects of thermal metamorphism. Basic volcanic rocks, pillow lavas and flows metamorphosed to amphibolites are exposed along the northwestern boundary of the survey area. The Archean rocks were deformed during the Kenoran orogeny (2390-2600 m.y.) into a series of steeply dipping or vertical isoclinal folds. A number of north-trending diabase and diabase porphyry dykes have been intruded into the Archean volcanic rocks.

The Coldwell alkalic complex comprises a suite of rocks ranging in composition from gabbro to syenite. Regionally, these form a large lopolithic intrusion and the contact between gabbro and Archean volcanic rocks is exposed in the central part of the survey area. The sequence of rock types southwestward from this contact is: chilled gabbro, a lower massive gabbro unit, a middle flow-layered gabbro unit, and an upper gravity-layered gabbro unit. The gabbro ranges in texture from fine- to coarse-grained and has a well-defined, transitional contact with massive, red syenite to the southwest. Texturally, the massive older gabbro is medium- to coarse-grained and consists of subhedral-equigranular plagioclase, clinopyroxene, olivine, and accessory mineral phenocrysts. Layered gabbro comprises alternating gabbroic and anorthositic units that trend northwest. Older parts of the layered sequence typically are discontinuous. Towards the top of the gabbroic rock sequence, stratified layering is well-developed and shows increasing uniformity with decreasing age. The contact between "older" layered gabbro and "younger" laurvikite (syenite) in general is apparently gradational, although chilling has been observed in places. The rocks throughout the contact zone are grey in colour.

In the survey area, the laurvikite is massive and pink coloured due to the presence the of hematite. The mineralogy is basically potassium feldspar, olivine, aegirine augite, magnetite, primary and secondary barkevikite, minor

zircon, rare earths, apatite, and chlorite. Locally, the laurvikite is layered and also occurs as pegmatitic dykes. These were probably emplaced along preexisting ring-like fractures during periods of local extension. Strong radial and concentric lineaments are clearly visible on air photographs in the southern half of the survey area.

Base metal sulphide mineralization, principally pyrrhotite, chalcopyrite and barite is distributed in the gabbro close to the contact with the Archean volcanic rocks. Disseminated chalcopyrite and iron sulphides occur in coarse and pegmatitic gabbroic phases. The sulphides may also replace mafic minerals within the gabbro and can be present in massive magnetite close to the intrusive contact (Carson 1953). Extensive diamond drilling by Anaconda Canada Exploration Limited and other companies has outlined several elongate zones of copper mineralization oriented parallel to the contact zone. The largest of these extends for roughly 300 m to the north and south of the principle mineral occurrence located in the centre of the survey area. There are several other small zones to the south of this occurrence. Maximum copper concentration in a typical drill hole intersecting the mineralized coarse-grained gabbro is 0.33% and the average abundance over an 80 m interval is 0.20%. Nickel content in the mineralized zones is less than 0.15%.

Numerous pyrite showings are present in the volcanic rocks outcropping in the northern part of the survey area. Pyrite and minor chalcopyrite are associated with zones of intense brecciation cutting altered volcanic rocks. At least one chalcopyrite-sphalerite showing has been reported in the volcanic rocks, although the exact location of this occurrence is uncertain.

Marshall Lake Area

The Marshall Lake survey area is a gently undulating plain with maximum relief of 50 m. A major topographic feature is the Gripp River which drains Marshall Lake and flows west into Gripp Lake. In addition to Marshall and McDermot Lakes, there are numerous smaller lakes and swamps throughout the area. The region to the north of the Gripp River is almost completely covered by sandy fluvioglacial material which is locally up to 30 m thick. Other fluvioglacial deposits include a large esker located on the south side of the Gripp River. This curves from the Gripp River in a gentle, south-trending arc and terminates near the mouth of the Marshall River. Outcrop is relatively common throughout the central part of the survey area forming low ridges which are separated by lakes, meandering streams or swamps. Sandy fluvioglacial deposits increase in thickness and lateral extent towards the south although bedrock areas are still frequently exposed. The extreme southern part of the area is largely covered by swamp through which the Marshall River flows.

The dominant soil type found on the better drained esker and other sandy fluvioglacial materials is an orthic humo-ferric podzol. A thin lithosol or total absence of soil is typical of areas where outcrop is exposed. Vegetation is typical of the northern boreal forest region and distribution tends to reflect soil type and drainage. Well-drained soils and immature profiles formed over outcrop support white spruce, black spruce and poplar. White birch and poplar with black spruce are more common in areas of thicker sandy material where soils are moderately

well-drained. Scattered black spruce and tamarack are the dominant species in swamps where the ground cover is almost entirely sphagnum moss. The proportion of deciduous to evergreen timber is roughly 60 to 40 percent.

The geology of the survey area shown in Chart F has been mapped and described by Amukun *et al.* (1976, 1978, 1979) and except for Middle-Late Precambrian diabase dykes, the rocks are all of Archean Age. In the centre of the survey area these rocks range from felsic to intermediate metavolcanics which exhibit a variety of features and structures. The geology has been interpreted as a thick volcanic pile produced from at least three volcanic centres on the south side of the Gripp River. These centres are defined by the dispersed areas of pumice fall deposits and coarse-grained pyroclastic rocks. Pyroclastic lithologies include submarine and subaerial intermediate to felsic pumiceous and vesicular pyroclastic flows, lava flows and related breccias. There are also several areas of coarse-grained fragmental rocks containing minor mafic metavolcanics. The felsic rocks are overlain by metasediments derived by erosion and redeposition of the earlier pyroclastics. Banded oxide facies (quartz-magnetite) and sulphide facies (pyrite-pyrrhotite and graphite) iron formation occur as distinct units within the metasediments and outcrop south of Marshall Creek in the southeast corner of the survey area. Biotite and chlorite zones having compositions characteristic of the greenschist metamorphic facies are present in the volcanic pile. Two semicircular gabbroic stocks are intrusive into the metasediments and metavolcanics on the north side of Marshall Lake and along the eastern boundary of the survey area.

The metavolcanics with associated sulphide bodies and metasediments have been folded into a regional anticlinal structure. The trace of the axial plain of the anticline, located south of Marshall Lake, strikes almost east-west and the axis plunges east at 35 to 45 degrees. Several later fold features have been superimposed on the broad regional structure. These include antiform-synform fold pairs, drag folds, chevron folds, and very complex crenulations. Some minor folds are often emphasized by quartz vein filling, and lineations associated with these folds are parallel to the plunge of the regional anticline. Base metal sulphide mineralization is often concentrated in the nose of minor folds.

Fault zones, clearly visible on air photographs, are the most obvious structural feature in the survey area. A pronounced fault, striking west-northwest, extends for 13 km from Banana Lake to west of Gripp Lake. Fault breccia is associated with this structure. Other fault and shear zones striking north-northwest, north-northeast, north-south, and east-west are characterized by schistose rocks (sericite and/or chlorite schists), structural offsets and topographic lineaments. Some of the fault zones are occupied by diabase dykes.

The base metal mineralization in the survey area is predominantly disseminated pyrite and/or chalcopyrite-sphalerite with minor galena and silver. Mineralization is assumed to be synvolcanic and related to formation of the volcanic centres. It is closely associated with garnetiferous amphibolite lenses composed of actinolite-tremolite, albitic plagioclase, muscovite, biotite, pyrochlorites, epidote, calcite, and quartz. Sulphides in many showings are confined to the noses of minor folds and probably reflect concentration during metamorphism and folding. Structural control of mineralization suggests an epigenetic type origin for these lenses, although the geology of the area is very similar to many other Precambrian environments where there are stratabound volcanogenic massive sulphide deposits.

Although disseminated base metal sulphides can be found in most outcrops, there are two principle areas where significant concentrations are known. The "Main" or Billiton (Canada Limited) showing (Amukun *et al.* 1978) south of Marshall Lake is principally black, disseminated sphalerite with associated chalcopyrite. Diamond drilling by several companies (Amukun *et al.* 1978) has established a reserve of 1.44 million tons grading 4.76% zinc, 1.45% copper and 2.8 ounces of silver per ton. This mineralized zone has a strike length of several hundred metres and extends vertically less than one hundred metres. Minor disseminated galena has been reported in a small occurrence to the north of the main zone which is close to the contact with a diabase dyke.

The second major mineralized center is west of the "Main" zone and south of Gripp Lake. Although extensive exploration has been conducted by Teck Corporation, no tonnage or grade estimations are available. However, diamond drilling has outlined four zones, one of which consists of massive chalcopyrite with traces of pyrrhotite and sphalerite. The zone is up to 6 m wide and several tens of meters long. Two other adjacent zones are not exposed at surface, but resemble the massive chalcopyrite zone in character. A fourth zone located 300 m to the east is characterized by sphalerite-bearing amphibolite stringers in felsic volcanic rocks. Despite the intensity of the sulphide mineralization, no significant wall-rock alteration has been reported.

RESULTS OF "GROUND TRUTH" SAMPLING

General Statement

"Ground truth" investigations consisting of forest litter and vegetation sampling were carried out in the two survey areas with the objective of determining the degree of element accumulation in the vegetation surface microlayer and possible redistribution of metals from decaying vegetation. Forest litter samples were collected by hand at intervals ranging from 50 to 100 m along traverses. Samples of new foliage from evergreen and deciduous trees were also taken continuously within the same intervals. Details of the analytical techniques are given in the section "Analytical Techniques" and raw element data are tabulated separately. The distribution of selected trace elements in the forest litter from areas immediately surrounding known mineralization are described and discussed in the section on "Description of Results". Horizontal variation of elements throughout the whole extent of the vegetation and forest litter sampling is described in this section.

Marathon Area

Horizontal variation of Cu,Ni,Ca, and Sr in forest litter over the Marathon survey area is shown in Figure 4, Chart K, back pocket. Contact between syenite and gabbro occurs at sample 31, and between gabbro and volcanic rocks at sample 1 which corresponds to the Anaconda Canada Exploration Limited

sulphide occurrence. The copper abundance in forest litter is relatively uniform over the syenite and increases, rather erratically, over the gabbro. Values decline along the northern part of the traverse underlain by thick fluvioglacial sands. The nickel distribution is highly erratic over rocks forming the alkaline complex and values demonstrate a general decrease to the north. A sharp Ni-Fe-Mg-Ti-V-Si anomaly directly over the sulphide occurrences can be explained by inclusion of mineral grains with the forest litter sample. Sr and to a lesser extent Ca show a concomitant increase above the gabbroic rocks. However, whereas Sr exhibits a relatively erratic distribution over the fluvioglacial materials to the northeast, Ca levels increase sharply to more than 2 percent. Other elements demonstrating a significant decrease from the alkaline complex to the sand covered volcanic rocks are Ti and V. The variation of Ca,Cu,Zn, and V over the three principle rock types covered by the ground survey is also shown by data from selected samples in Table 4.

A comparison is also made in Table 4 of the metal abundances in forest litter and vegetation leachates. In general, there is little detectable difference between Ca and Cu in leachates from vegetation growing on the syenite and gabbro compared to the volcanic rocks. However, Sr and V in leachates and forest litter material are consistantly higher over the gabbro compared to other rocks. Other elements in vegetation leachates, apart from those described above, are either below instrument detection level or demonstrate no significant change. The general enhancement of Sr and V in vegetation leachates and forest litter over the gabbroic rocks is also reflected in higher levels of these elements in the micro-layer samples collected with the airborne system. This relationship is demonstrated by the horizontal variations of elements along one flight line which approximately parallels the ground truth traverse shown in Figure 5, Chart K, back pocket. Also demonstrated in Figure 5 is a marked inverse relationship between Ca in forest litter and Ca in vegetation SURTRACE samples. Why this relationship should prevail and its significance, if any, remain unknown.

Marshall Lake Area

The distribution of Cu,Zn,Ca, and Mn in forest litter along the two parallel ground traverses extending from metasediments in the south to the "Main" sulphide zone in the north is shown in Figure 6, Chart K, back pocket. Although there is little significant variation of Cu and Ca; Zn and Mn demonstrate a concomitant increase over the mineralized zones. The correlation between these two elements is especially marked along the eastern line. Raw element data for forest litter and vegetation leachate samples shown in Table 5 indicate that there is little difference in element abundances over the two major rock types. Also, variations of elements do not reflect changes of secondary environment such as the presence of swamp which is continuous along the western line between samples 119 and 137.

TABLE 4 - TRACE ELEMENTS IN VEGETATION LEACHATE AND FOREST LITTER SAMPLES MARATHON SURVEY AREA

Sample Number	Ca (V) %	Ca (F) %	Cu (V) ppm	Cu (F) ppm	Sr (V) ppm	Sr (F) ppm	V (V) ppm	V (F) ppm	Rock Type
1-2	0.11	0.29	1.3	22.8	7.7	19.1	0.14	158	G
3-4	0.13	0.57	1.9	12.7	5.9	27.3	0.11	13	G
5-6	0.13	0.44	1.8	12.4	6.8	18.4	0.17	13	G
7-8	0.12	0.71	1.2	24.6	9.5	51.7	0.05	11	G
9-10	0.25	0.76	3.3	13.1	21.2	44.4	0.23	14	G
11-12	0.25	0.53	3.1	16.7	26.6	40.8	0.14	15	G
59-60	0.04	0.09	0.5	8.8	0.9	4.6	0.04	14	S
61-62	0.12	0.25	1.6	9.0	2.3	9.6	0.14	10	S
63-64	0.08	0.44	0.9	10.8	2.0	15.4	0.09	11	S
65-66	0.07	0.52	0.6	10.6	1.5	15.8	0.05	13	S
67-68	0.07	0.43	0.8	9.2	1.7	12.1	0.10	15	S
107-108	0.09	2.01	0.9	10.2	2.1	12.8	0.04	6	V
109-110	0.07	1.33	0.7	9.5	2.2	10.9	0.05	3	V
111-112	0.06	1.30	0.6	7.7	2.2	14.1	0.05	4	V
113-114	0.14	1.77	1.6	11.0	4.4	16.2	0.05	4	V
115-116	0.18	0.63	2.0	6.9	4.9	10.6	0.08	2	V
117-118	0.13	1.31	1.0	9.7	3.5	16.7	0.09	5	V

(V) = Vegetation Leachate
(F) = Forest Litter Sample
G = Gabbro
S = Syenite
V = Metavolcanic Rock

TABLE 5- | TRACE ELEMENTS IN VEGETATION LEACHATE AND FOREST LITTER SAMPLES MARSHALL LAKE SURVEY AREA

Sample Number	Ca (V) %	Ca (F) %	Cu (V) ppm	Cu (F) ppm	Mn (V) ppm	Mn (F) ppm	Zn (V) ppm	Mn (F) ppm	Rock Type
1-2	0.09	1.54	0.8	8.3	310	553	32	261	V
3-4	0.10	0.36	0.6	4.5	366	262	26	91	V
5-6	0.10	1.06	0.8	7.4	255	1050	24	134	V
7-8	0.11	0.87	0.8	7.0	421	478	33	149	V
9-10	0.25	0.68	0.8	7.6	72	1360	34	84	V
11-12	0.10	2.25	0.4	3.5	361	317	24	42	V
13-14	0.11	0.46	0.6	7.0	368	587	41	79	V
15-16	0.09	1.73	0.6	6.1	268	161	29	32	V
65-66	0.11	1.12	0.4	3.6	264	402	34	60	S
67-68	0.10	0.93	0.8	8.5	320	508	24	57	S
69-70	0.09	0.84	0.6	6.4	376	859	19	51	S
71-72	0.12	1.27	1.2	5.3	421	393	20	60	S
73-74	0.11	0.51	0.4	5.2	611	215	16	35	V

(V) = Vegetation Leachate
(F) = Forest Litter Sample
V = Metavolcanic Rock (Unit 2)
S = Metasedimentary Rock (Unit 3)

DESCRIPTION OF RESULTS

General Statement

Procedures for describing and interpreting geochemical data collected by conventional sampling methods over areas of known or potential sulphide mineralization are well established. Preliminary evaluation usually involves discriminating between "normal" or background and anomalous element abundances using statistical procedures such as frequency histograms. Moreover, the significance of a geochemical anomaly can be further established by comparing the ore-related metal distribution patterns with the multi-element signature in the material sampled. This can often distinguish areas underlain by a particular rock type from areas containing base metal sulphides. Conventional methods of treating geochemical data are less applicable to airborne SURTRACE surveys for several reasons:

(1) Element concentrations are measured semiquantitatively using the LASERTRACE method. For this reason, the relative variation in element abundances in the vegetation microlayer is more important than absolute abundances as commonly employed in conventional geochemical surveys.

(2) Accumulation of metals in the vegetation microlayer will depend on a number of factors such as vegetation species, plant physiology and soil profile maturity, in addition to geological changes and presence of sulphide mineral concentrations. Therefore, the element distribution patterns outlined by airborne SURTRACE sampling may have an indirect relationship to the underlying bedrock and soil geochemistry.

(3) The airborne SURTRACE sample density is far less than that normally encountered in conventional soil sampling surveys where the area sampled is generally restricted to a number of mineral claims. However, continuous-mode airborne sampling is similar to rock-chip channel sampling in that element abundances are averaged over a linear interval. Consequently, small high-contrast anomalies which would be expected over discrete sources on the ground such as narrow, elongate sulphide mineral zones will be depressed or obscurred in SURTRACE sampling.

(4) Element anomalies in conventional geochemical survey data are frequently defined by arbitrary threshold values at the arithmetic or geometric mean plus two standard deviations. These statistics are generally calculated or estimated from frequency histograms plotted from raw element data. Airborne SURTRACE geochemical anomalies can be outlined by the same criteria since the raw millivolt data are normalized and presented in terms of standard deviations on the line-printer maps. Although values greater than mean plus 2.5 standard deviations are a significant departure from "normal" levels, the strength of an anomaly will depend on the analytical sensitivity. Variations in those elements which have a signal response much lower than the blank (i.e. Cd,Mo,Ag,Th) may largely be due to instrumental noise during analysis.

In this report, a preliminary evaluation is made of the available lithogeochemistry, subsurface soil geochemistry, and surface soil geochemistry, within small study regions surrounding known base metal sulphide mineralization in the two survey areas. The object of this comparison is to establish the surface

geochemical expression of known mineralization which is then compared to the observed SURTRACE geochemical response. Models are thus established and can be extended to describe and interpret the airborne SURTRACE element distributions outlined on a regional basis within the two survey areas.

Marathon Area

Characteristics and Detailed Geochemistry of the Sulphide Mineralization

A detailed sketch of the geology and environment of the principal (Anaconda Canada Exploration Limited) base metal occurrence in the Marathon survey area is shown in Figure 7. Sulphide mineralization at this locale consists of disseminated pyrrhotite and chalcopyrite in coarse-textured gabbro close to the contact between the Coldwell alkaline complex and Archean volcanic rocks. The mineral zone is 10 to 20 m wide and roughly 600 m long, although scattered pyrite and chalcopyrite are present more or less continuously along the contact. Surface weathering of the gabbro host rock is moderately intense. Soils range from immature profiles where weathered bedrock is exposed to mature profiles where there is greater overburden thickness. The sulphide mineral zone is aligned parallel to magnetic contours on the flank of a major airborne magnetic high (G.S.C. Aeromagnetic Map 2157G). This anomaly reflects concentrations of magnetite along the contact and within the gabbro.

Conventional soil sampling has been carried out over the sulphide mineralization, but results of the survey are unavailable. However, rock geochemistry studies have been made (Sage 1979; Whittaker 1976) and data from selected samples collected close to the mineral occurrence are shown in Table 6. These data emphasize the high calcium content of the gabbro and also the enhanced Cr and Ni levels typical of this rock. Copper content is less than 350 ppm, although assay values of up to 0.33 percent have been reported for the sulphide mineral zone (Carson 1953). Variation of elements in forest litter samples northeast and southwest of the sulphide mineral zone along a traverse indicated on Figure 7 is shown in Table 7.

Examination of data shown in Table 7 indicates that Fe,Cu,Ti,V,Cr, and Ni are enhanced in sample CC-1 collected over the sulphide zone. However, this sample is suspect because the concomitant increase of Si in the material probably reflects inclusion of mineral grains with the organic matter, which could also explain the concentration of other elements. Samples collected within 50 m of the sulphide zone show no increase in element abundances indicating that, at best, there is only a very local surface expression of the mineralization. A comparison between the forest litter Cu values (in ppm/10) and the element response in the airborne SURTRACE samples (in millivolts), collected along a flight-line crossing the mineralization, is shown in Figure 8. The average Cu value for five forest litter samples is plotted at a single point to provide a closer comparison with the SURTRACE sample interval. The detailed area covered by the forest litter and SURTRACE profiles extends from the syenite into the metavolcanics and is outlined in Chart A, back pocket.

Copper distribution in both SURTRACE and forest litter samples shows very little variation from the syenite, to the gabbro, to the Archean metavolcanics; nor

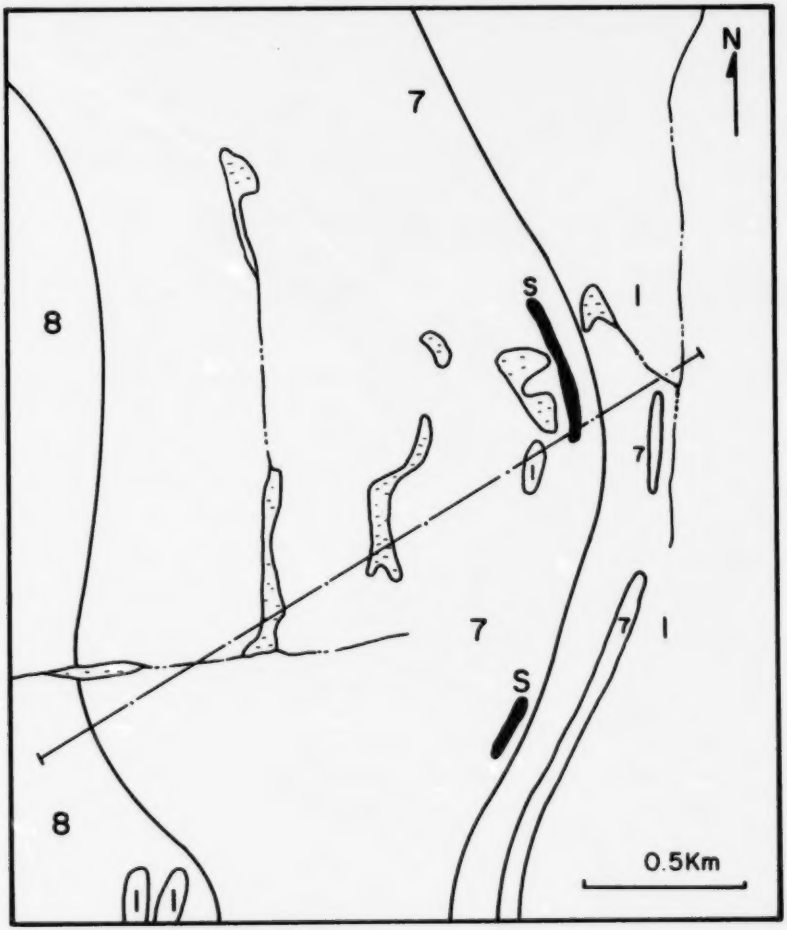


Figure 7—Sketch map of the geology of the Anaconda Canada Exploration Limited occurrence, Marathon area.

TABLE 6- GEOCHEMICAL DATA FOR GABBRO AND SYENITES FROM THE COLDWELL COMPLEX, SAMPLES COLLECTED 20-30 METERS SOUTH OF THE "MAIN" OCCURRENCE (FROM SAGE 1979; WHITTAKER 1976).

Sample Number	Rock Type	CaO %	MgO %	SiO_2 %	Co ppm	Cr ppm	Cu ppm	Ni ppm	Zn ppm
3584	MG	12.1	8.12	47.4	51	138	350	125	76
3589	FG	9.84	14.3	46.2	78	200	30	500	105
3590	MG	12.8	5.30	46.1	42	94	110	89	126
78 - 78	PG	15.28	8.71	46.55	52	178	120	—	78
W-14-3	S	3.43	0.34	57.15	—	—	—	—	—
W-7-3	S	2.60	0.47	57.93	—	—	—	—	—
3620	S	2.97	0.35	58.5	<5	< 3	197	< 5	250
3621	S	10.2	0.33	44.9	39	146	280	60	230
3609	S	2.62	0.09	60.8	<5	7	17	< 5	145

MG = Medium-grained Gabbro
FG = Fine-grained Gabbro
PG = Pegmatitic
S = Syenite

TABLE 7- VARIATION OF METALS IN FOREST LITTER OVER SULPHIDE MINERALIZATION,MARATHON AREA.

Sample Number	Al	Ca	Cu	Fe	Mn	Si (ppm)	Ti	V	Co	Cr	Ni	Location
CC-17	2910	3200	10.3	3150	573	71.2	199	10.5	1.8	5.78	5.7	400 m S
CC-15	6210	6540	16.1	11600	2000	97.4	703	32.8	7.5	13.0	12.6	350 m S
CC-13	4210	4900	17.7	4960	476	70.9	178	23.4	2.6	7.90	12.3	300 m S
CC-11	3940	5250	16.7	3990	4860	45.1	154	16.8	4.2	8.15	7.7	250 m S
CC-9	3540	7570	13.1	3980	2360	70.5	157	16.3	2.6	6.00	8.7	200 m S
CC-7	1950	7070	24.6	2720	493	92.2	102	10.5	2.1	4.99	7.6	150 m S
CC-5	2990	4410	12.4	3620	563	42.7	151	13.3	2.3	5.95	9.4	100 m S
CC-3	2410	5730	12.7	3230	485	56.9	204	13.0	2.3	5.16	7.7	50 m S
CC-1	4100	2910	22.8	88200	1340	253	1920	158	96.7	16.3	127	0*
CC-81	937	7380	10.6	1200	1170	39.4	38.8	5.27	0.8	3.4	5.7	50 m N
CC-83	1490	5010	14.6	1880	278	36.0	57.5	7.52	0.8	4.42	6.5	100 m N
CC-85	2380	4240	13.0	2880	185	67.8	95.0	10.6	0.9	6.32	6.6	150 m N

(*) Mineral Occurrence

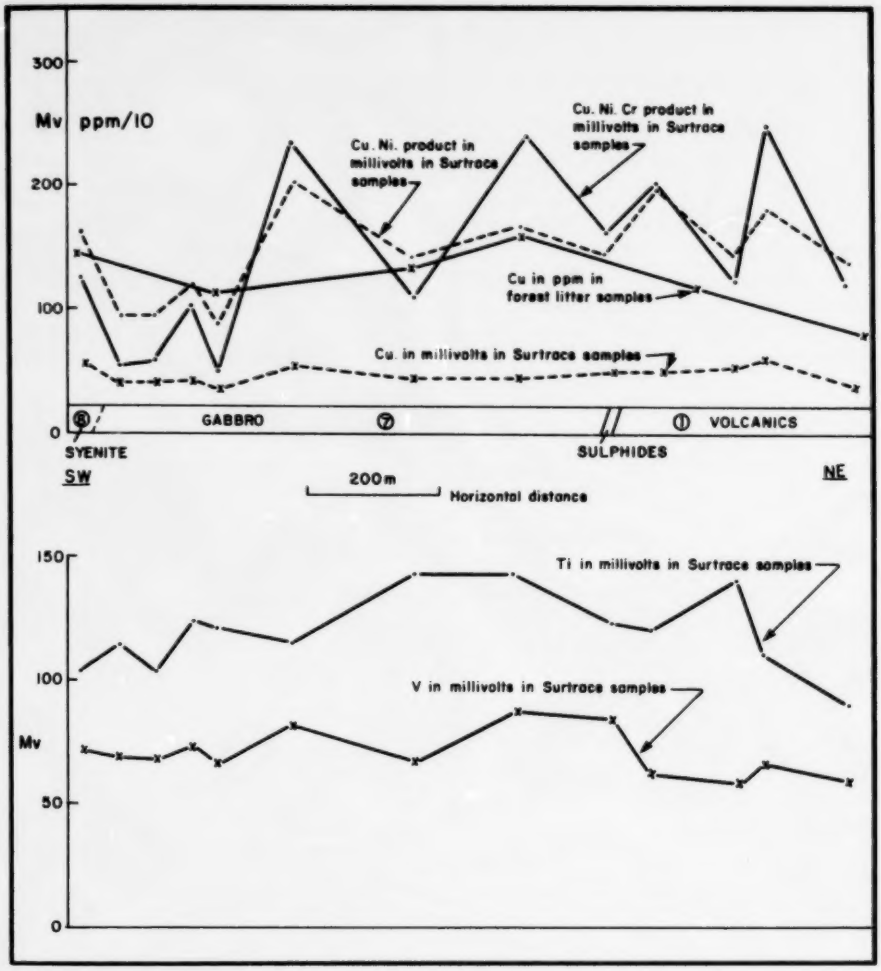


Figure 8—Detailed variation of elements in airborne microlayer and forest litter samples over sulphide mineralization, Marathon area.

does it indicate the presence of mineralization. However, two additional SURTRACE profiles are presented illustrating the Cu.Ni and Cu.Ni.Cr products. These demonstrate an increase over the gabbro compared to the syenite, although the decrease of element products to the northeast does not correspond to the geological contact. The higher product values over the gabbro are also reflected in increased levels of Ti and V.

The spatial relationship between Cu.Ni SURTRACE anomalies (greater than the mean plus 2.5 standard deviations) and the base metal sulphide zone within

an area typical of several mineral claims is illustrated in Figure 9. This figure demonstrates that over a relatively small area surrounding the occurrence, one airborne Cu.Ni SURTRACE anomaly with enhanced levels of Ti, V and Cr occurs directly over one end of the sulphide zone, and several others are close to the

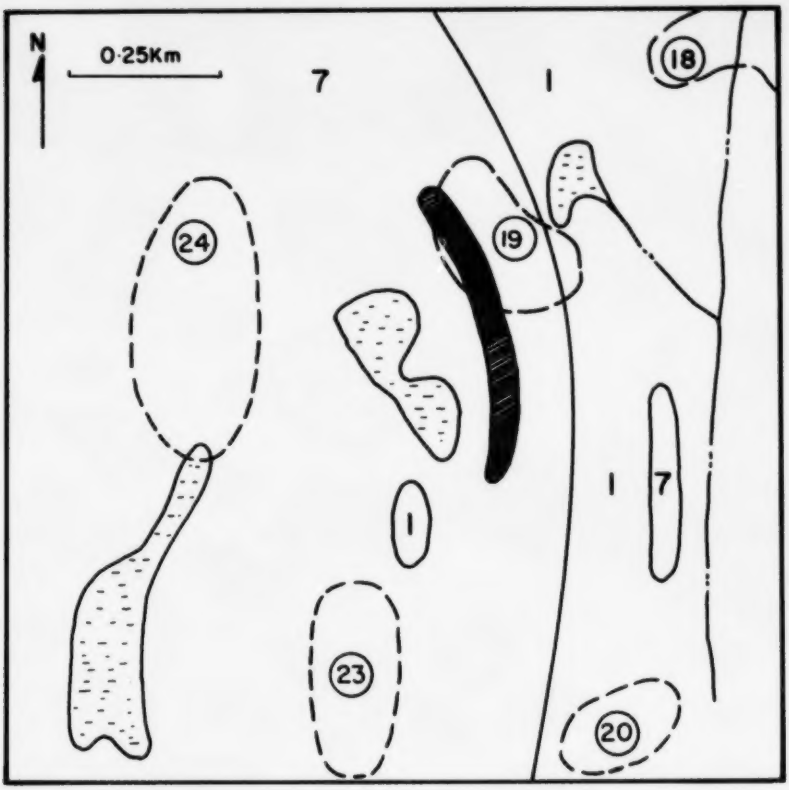


Figure 9—Detailed sketch illustrating airborne SURTRACE patterns over the Anaconda Canada Exploration Limited occurrence, Marathon area.

contact between the gabbro and volcanic rocks. Thus, exploration targets are detected by the airborne SURTRACE patterns and could be enhanced by more detailed geophysical or geochemical techniques.

Regional Airborne SURTRACE Geochemical Patterns in the Marathon Area and Description of Anomalies

Hand-contoured maps for Cu,Ni,Ca, and Sr (see Charts B,C,D,E; back pocket) are presented to illustrate the more significant features of the geochemical landscape. The most obvious feature demonstrated by these maps is the marked regional variation of Ca and Sr levels over the survey area. These elements are typically below 0.5 standard deviations in the northeastern part of the survey area, but increase to more than mean plus 1.5 standard deviations in the southwest. Calcium demonstrates the most consistent increase and the averaging procedure was applied to smooth contours for this element. Contours for values greater than mean plus 1.5 and 2.5 standard deviations are shown on Chart A which also has geological contacts and principal mineral occurrences. The contact between the gabbro and metavolcanics parallels the 1.5 standard deviation contour, while the gabbro-syenite contact follows the 2.5 standard deviation contour for much of its length across the survey area. However, Ca levels apparently decrease from an arcuate zone of high values to a low in the southwestern corner of the survey area. This zone of high Ca is reflected by concomitant increase of Sr and also V.

Principal element anomalies are also shown on Chart A, back pocket. The areas outlined have Cu.Ni products or Cu values greater than mean plus 2.5 standard deviations. Emphasis has been placed on these anomalies which persist across several flight lines. Single-point anomalies, except where very high metal values are indicated, have not been included. The outline of anomalies should be compared with contoured Cu and Ni maps.

A high contrast Cu.Ni anomaly (No.19) with values exceeding 9 standard deviations occurs over the main mineral occurrence and is associated with enhancement of Cr,Fe,Mn,Ti, and V. Lower element levels outline a general zone extending north and south where there are other significant Cu.Ni anomalies (Nos.18,24). Several smaller Cu and Cu.Ni anomalies occur along or close to the gabbro-volcanic rock contact (Nos.17,20,28,30,31). Although the peak of the anomaly is indicated as a single point, larger zones defined by values exceeding 1.5 standard deviations extend across flight lines and roughly parallel the strike of the contact. Two prominent Cu.Ni anomalies (Nos.27,24) occur within the area underlain by gabbro, but south of the contact. Anomaly 27, for example, has a strong Cr association whereas anomaly 24 has concomitant increase of Cr,Fe and Ti.

Element anomalies in the area underlain by syenitic rocks demonstrate two marked trends. Several strong multi-element anomalies (Nos.37,38) are parallel to flight lines. This is a common feature of airborne geochemical data and is probably a memory effect. Although exact causes are presently unknown, the memory effect may be partially due to incomplete backflushing of particles from the sample probe assembly between sampling periods. A second contributing factor could be minor condensation of volatiles produced by laser vapourization of material from the tape before introduction into the RF argon plasma. This

latter factor is only apparent when a sample is preceeded by another sample of very high relative concentration (x5). However, memory effect anomalies can be readily detected by their strong "line-parallel" orientation and concomitant increase of many minor and trace metals. Other anomalies in this area demonstrate a strong, cross-line, southwest trend. Examples are Nos.33,40,91 and 42. Anomaly 40 extends for roughly 1 km along this trend and has a strong association of Cu and Ni with Cr,Mn and Ti. There is some evidence of zonation with higher Ni to the southwest and increased Ca to the northeast. A similar multi-element association is shown by anomaly 42 which has a Cu.Ni product greater than 9.5 standard deviations.

There are a number of prominent multi-element anomalies northeast of the gabbro in an area concealed by glacial deposits. The largest of these (No.11) is a strong Cu-Ni-Fe-Mn anomaly which trends east-west and persists for 2 km. The main portion of this anomaly appears to follow the Goodchild Creek valley.

Anomaly No.18 is smaller, has an arcuate shape, and is located directly north of the main mineralization. Several of the Cu.Ni anomalies east of the Pic River (Nos.5,7,8) display a strong line-parallel orientation although there are also zones crossing flight lines along a southwest trend (No.14).

In the northern part of the survey area where volcanic rocks are partially exposed, three prominent multi-element anomalies can be defined and also several single-point copper anomalies. Anomaly 1 shows enhanced levels of Cu, Ni,Zn and Cr and extends for roughly 2 km along a north-northwest trend. Anomalies 2 and 3 are smaller, but also have similar association of Zn with the Cu and Ni. There are also several moderate contrast Cu anomalies to the east although these have not been indicated on Chart A, back pocket.

Marshall Lake Area

Characteristics and Detailed Geochemistry of the Base Metal Sulphide Mineralization

General geology, distribution of base metal sulphide mineralization, and secondary environment of the Marshall Lake survey area are described in the section on "Topography, Overburden, Vegetation, and Geology". Spatial distribution of the base metal occurrences, soil types and surficial deposits of a detailed area surrounding the "Main" (Billiton Canada Limited) sulphide zone are shown in Figure 10. The "Main" sulphide zone trends northeast and, although less than 50 m wide, it is more than 300 m long. There are several smaller base metal occurrences to the north and south of the "Main" zone. All the major sulphide occurrences including the "Main" zone are distributed along the flanks of a regional, arcuate, airborne magnetic anomaly which reflects the east-west trending fold structure dominating the survey area (O.G.S. Aeromagnetic Maps P.1588,P.1589,P.1593,P.1594). Although no lithogeochemical studies have been made over the area, a small soil geochemical survey has been conducted over the "Main" sulphide zone by St. Joseph Explorations Limited (Rayner 1974). The extent of this survey is indicated on Chart F. Spatial distribution of the base metal sulphide mineralization, soil types and surficial geology of the area covered by the survey are indicated in Figure 10.

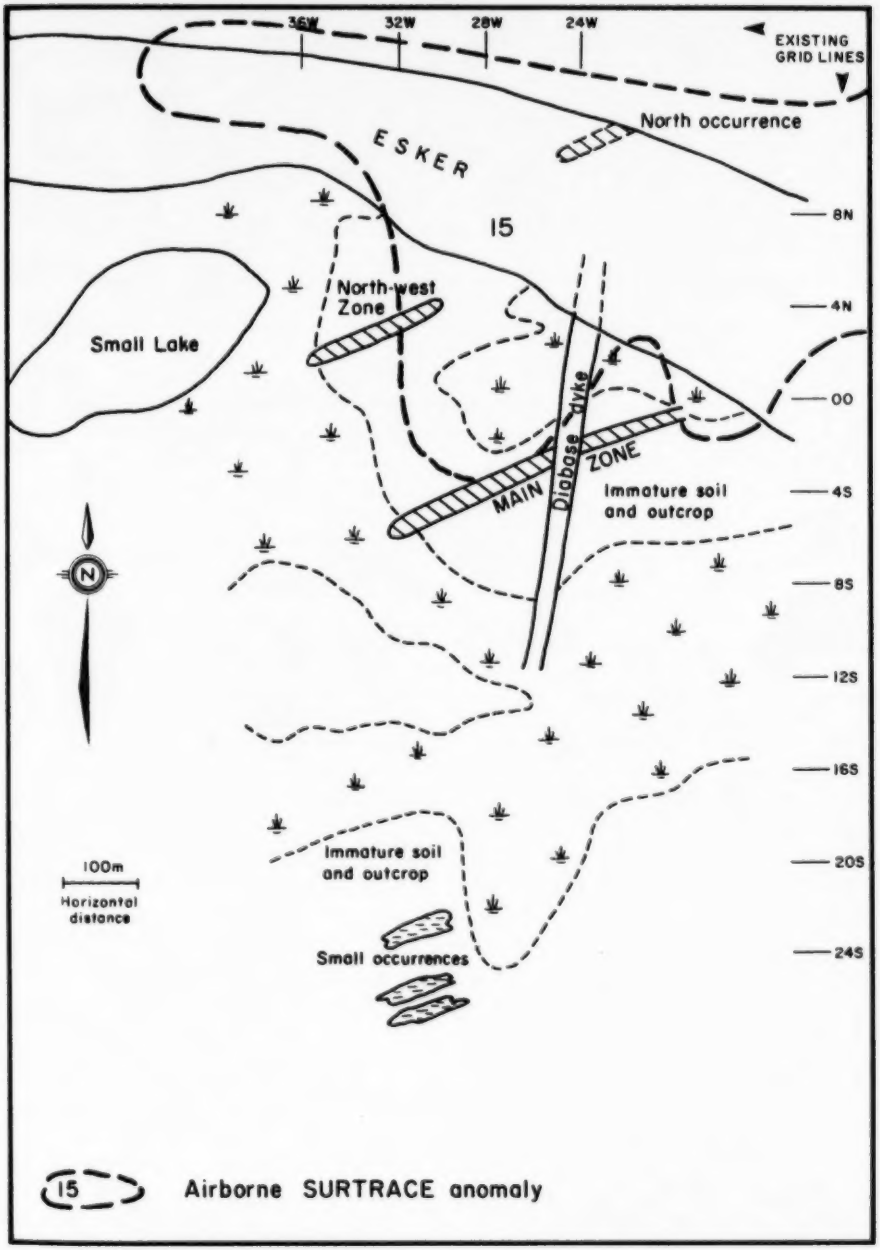


Figure 10—Detailed sketch of the "Main" (Billiton Canada Limited) sulphide zone and its environment, Marshall Lake area.

Horizontal distribution of Cu and Zn in conventional ('B' horizon) soil samples collected along two north-south oriented traverses, one crossing the "Main" zone, is shown in Figure 11. A strong Zn soil anomaly with values greater than 500 ppm occurs directly over the sulphide mineralization on grid line 32W at 8S. There is no comparable enhancement of Cu at this location although prominent Cu-Zn "rabbit ear" anomalies are present at locations 10S and 5S on the flanks of the principal Zn peak. Despite the high contrast of the Zn soil anomaly at 8S, the metal enrichment extends only 50 m beyond the limits of the sulphide mineralization. Total width of the Cu-Zn anomaly is, therefore, less than 300 m. In addition to the soil anomaly on grid line 36W over the "Main" sulphide zone, there are two Zn anomalies of similar contrast over smaller sulphide occurrences between 25S and 30S.

Conventional soil sampling was only carried out along part of grid line 36W because there is extensive swamp to the north of station 10S. No sulphide mineralization is indicated in the area crossed by this soil traverse, although the Zn soil anomaly at 14S may reflect a strike extension of the "Main" sulphide zone. Similarly, a second Zn anomaly at 27S could be explained by an extension of small sulphide occurrences detected along line 32W.

Comparison between the distribution of Cu and Zn in conventional soil samples, and Cu and Zn in forest litter samples collected over part of line 36W is also shown in Figure 11. There is very little variation of Cu in the forest litter despite a small conventional soil Cu anomaly at 15S. Horizontal variations of Zn in forest litter and conventional soil samples demonstrate a partial similarity which is most evident at station 14S. The variation of Cu and Zn in forest litter samples collected along grid line 36W is compared to the horizontal variation of these metals in the SURTRACE samples. These profiles are shown in Figure 12 where plotted forest litter metal abundances represent an average of three individual sample values. The object of this averaging is to provide composite data similar to the semicontinuous sample collected by SURTRACE and thus enable comparison of the various sampling procedures.

Both SURTRACE Zn and forest litter Cu show no significant variation over the strike extension of the sulphide mineralization. The SURTRACE Cu exhibits a greater response and moderately strong peaks correspond to the strike extension of the sulphide mineralization, and to an area where there are numerous faults south of station 30S.

The spatial distribution of SURTRACE Cu anomalies (defined by values greater than mean plus 2.5 standard deviations) is shown in Figure 13. This demonstrates that although Cu enhancement occurs over the esker to the north of the "Main" zone, there is no airborne SURTRACE anomaly directly over the exposed mineralization.

In summary, the conventional geochemical expression of base metal sulphide mineralization is in the form of narrow, high contrast Zn and lower contrast Cu anomalies corresponding to the outcrop of the sulphide mineral zone. There is a moderate although not completely consistent correlation between soil Zn and forest litter anomalies. Within the area immediately surrounding the "Main" base metal sulphide zone, increased SURTRACE Cu levels reflect increased thickness of overburden rather than presence of known sulphide mineralization. However, a general spatial relationship between raised SURTRACE Cu levels and the greater area of mineralized ground is present.

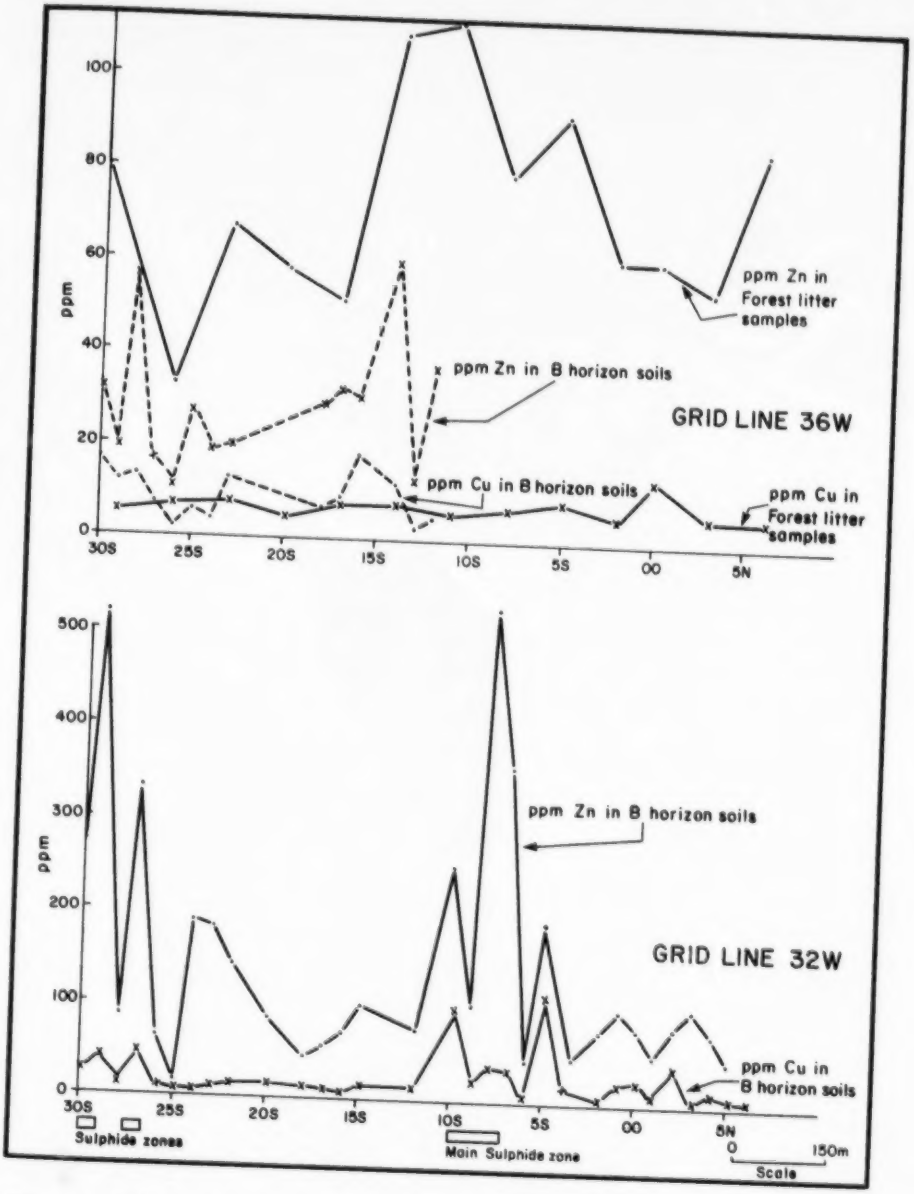


Figure 11—Variation of Cu and Zn in forest litter and 'B' horizon soil material over sulphide mineralization, Marshall Lake area.

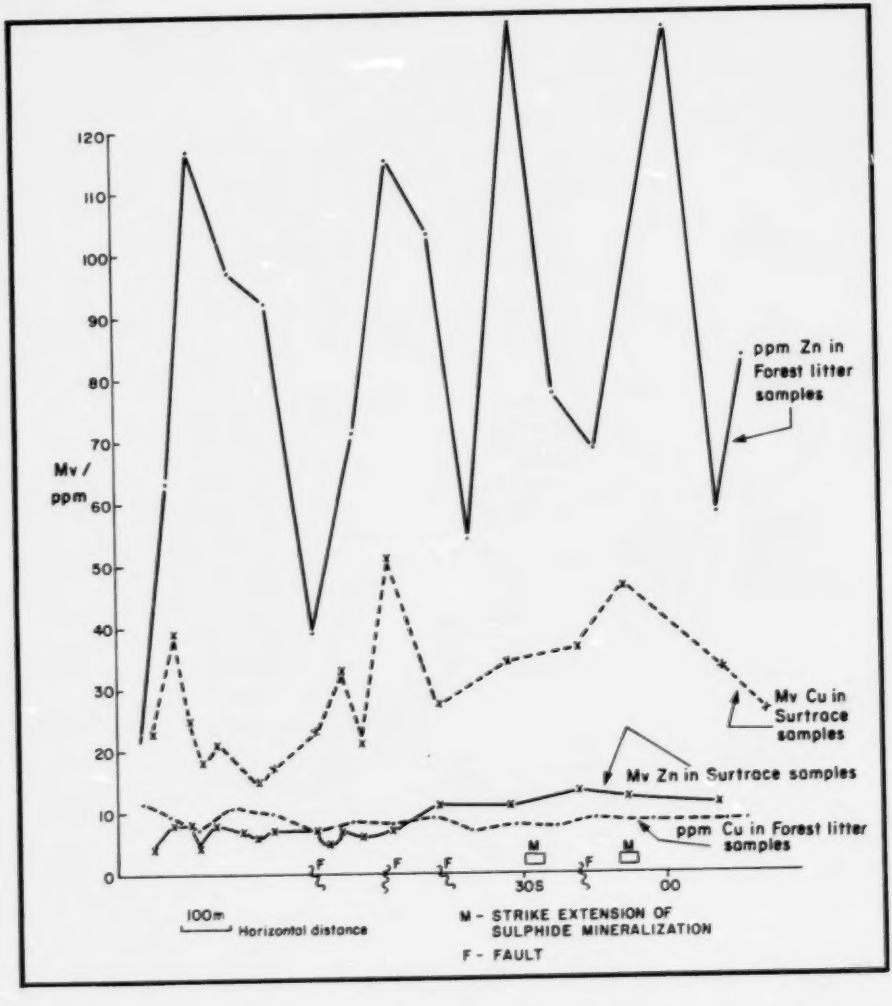


Figure 12—Variation of Cu and Zn in forest litter and airborne SURTRACE samples along traverses over sulphide mineralization, Marshall Lake area (metal values in forest litter are average of three samples).

Regional Airborne SURTRACE Geochemical Patterns in the Marshall Lake Area

Hand-contoured maps for Cu,Zn,Si, and Ca are presented to illustrate SURTRACE geochemical responses in this area. The same approach used to describe element anomalies in the Marathon survey area has been applied to the Marshall Lake area. Anomalous areas outlined in Chart F are those where the product of

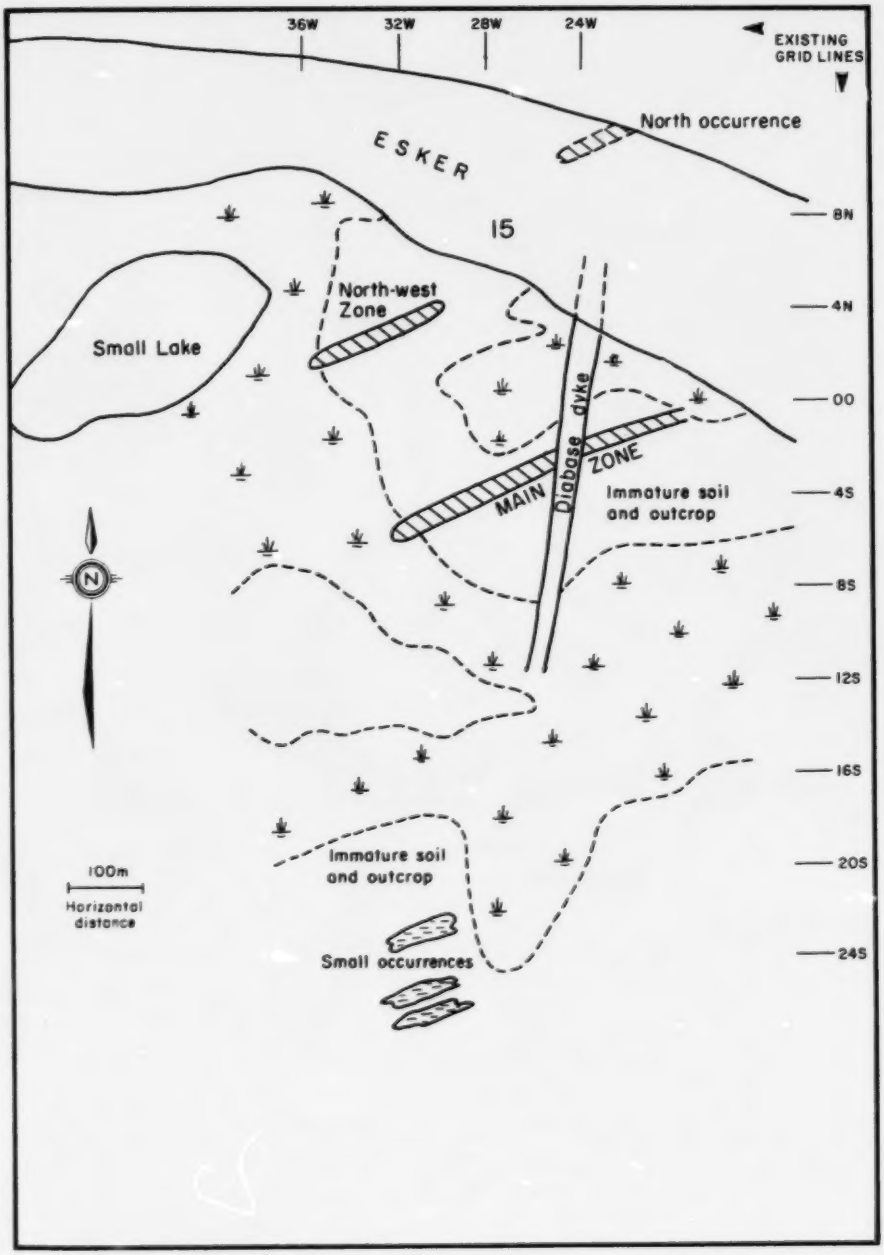


Figure 13—Detailed sketch illustrating SURTRACE patterns over the "Main" sulphide occurrence, Marshall Lake area.

Cu and Zn is greater than arithmetic mean plus 2.5 standard deviations. Also shown are areas where there is a similar degree of either Cu or Zn enhancement in the vegetation surface microlayer. The basic geology and spatial distribution of surficial deposits is also shown in Chart F.

The most prominent anomaly feature is a large zone of multi-element enrichment in the western half of the survey area, extending south from Gripp River and covering roughly twenty square kilometers. The outline of this metal rich zone which encloses Cu.Zn anomalies Nos.20-25 is shown in Chart F. The boundary of this zone is largely defined by the mean plus 1.5 standard deviations contour for Al and Ca. Inside this boundary is a smaller Si pattern for which the 1.5 standard deviation contour generally follows that of the other major elements. The Cu.Zn anomalies defined by a Cu.Zn product greater than mean plus 2.5 standard deviations are all enclosed by the mean plus 1.5 standard deviations Cu contour which, again, follows the general major element pattern. Significantly, the Teck Corporation and associated mineral occurrences occur within this major element enrichment feature.

Individual Cu.Zn anomalies within the boundary of the multi-element enrichment feature extend across three or more flight lines and are therefore highly significant because the statistical probability for chance occurrence of anomalous metal values on adjacent lines is extremely small. Anomaly No.20 occurs over the swampy margins of the Gripp River and is associated with concomitant increase of Si,Al,Mg,Fe,Mn, and Ba. Anomaly 21 is located over a similar swampy environment and is associated with enhanced Pb,Ca and Mn levels. Anomaly 22 trends northeast and extends for roughly 2.0 km crossing five flight lines. Pb,Ba,Si,Mn, and Fe levels greater than mean plus 2.5 standard deviations also follow this trend. Anomaly 23 has a distinctive triangular shape and also trends northeast for approximately 2.0 km. Principle elements associated with the Cu and Zn are Ba,Si,Al, and Mg. A high contrast (+3.5 standard deviations) Cu.Zn product defines anomaly 24 which extends across two flight lines and encloses the most westerly volcanic centre. Anomaly 25 is of similar size to 29 and the eastern end shows a concomitant increase of Fe,Mn and Ba.

A prominent multi-element anomaly parallel to the flight-line direction occurs along the eastern edge of the large multi-element enriched zone and extends for roughly 4 km. A similar line-parallel feature, where all elements show considerable enhancement, forms the western edge of the arcuate shaped anomaly 12. Despite the regularity of this line-parallel feature, two strong Cu.Zn peaks occur at the northern and southern ends.

The boundary of anomaly 15, defined by normalized Cu values greater than 2.5 standard deviations, crosses the northern edge of the "Main" sulphide zone. Although there is no detectable airborne SURTRACE anomaly directly over the "Main" zone, higher Cu and Cu.Zn product values enclose the easterly volcanic centre and two smaller base metal occurrences. The anomaly also corresponds to a portion of the east-west trending esker which crosses the survey area. A subdued Cu anomaly (13) with values greater than 1.5 standard deviations is located roughly 500 m south of the "Main" zone and trends east-west.

In addition to anomaly 15, several other SURTRACE patterns demonstrate a close or partial spatial relationship with the esker. These include anomaly 4 where there is a concomitant increase of Ba,Cu and Zn; and anomaly 5 which demonstrates a strong multi-element enhancement with high Pb levels at the eastern edge of this pattern.

In the southern part of the survey area, there are a number of prominent cross-flight-line anomalies which extend for several kilometers along an east-west trend. Anomaly 6, for example, consists of an eastern lobe orientated parallel to the contact between metavolcanics and metasediments. However, the western edge shows strong enhancement of multi-elements and these parallel one flight line. Increased levels of Fe and Mn define a northwest trend through anomaly 7 and enhanced Ca,Al,Fe,Mn, and Ba values coincide with the anomalous Cu.Zn products which define anomaly 8. The peak of anomaly 9 extends for 3 km along an east-west trend with a Cu.Zn product up to 4.5 standard deviations. Zn levels are higher at the eastern end of this zone whereas Cu is greatest to the west. Two small Cu and Cu.Zn anomalies (31 and 32) further to the west are also aligned along the same trend as anomaly 9.

Anomaly 10 demonstrates a relatively strong east-west trend although the eastern end is truncated by a strong multi-element feature parallel to a flight line. Anomaly 11 is essentially one of Zn enrichment with higher Cu.Zn product values in the southern part. Anomaly 27 is a relatively broad feature extending across two flight lines. Concomitant increase of Fe,Mn,Si,Al,Mg,Ca, and Ba defines a strong northwest-southeast trend. Anomaly 28 is of similar size and contrast, but does not exhibit a multi-element association. Anomaly 29 resembles 27 in having a significant multi-element association and extending across three flight lines.

Eight principle SURTRACE anomalies can be outlined in the area largely underlain by fluvioglacial outwash sands of variable thickness. The largest anomaly (No. 1) has an irregular shape and consists of a northern and southern lobe. The northern lobe extends along a west-northwest trend for roughly 4 km with Cu.Zn product values exceeding 3.5 standard deviations. A strong multi-element anomaly extends to the south and parallels one flight line. Lower Cu and Zn values, increasing to the west, define an east-northeast trend which crosses the southern end of the line-parallel multi-element anomaly. Anomaly 2 comprises an east-west Cu.Zn zone truncated at the eastern end by a strong north-south line-parallel feature. The highest Cu.Zn product values within anomaly 3 occur to the east on the contact between a small gabbro intrusion and older pyroclastic rocks. Lower Cu,Zn and other element values define a westerly extension from this peak.

Anomalies 16,17 and 26 all occur over extensive fluvioglacial sediments. Anomaly 17, for example, trends northwest and is in part associated with a strong multi-element line-parallel anomaly. Anomaly 26 is of similar size and trend with a smaller zone multi-element association within the centre of the Cu.Zn enhancement.

DISCUSSION OF RESULTS

General Statement

Interpretation of data from conventional geochemical surveys is often straightforward because there is considerable understanding of the processes by which elements are transported and concentrated in the secondary environment. The shape, contrast and multi-element signature of soil anomalies fre-

quently provides a direct indication of the location and nature of the mineralized source in bedrock. Element concentrations in vegetation and particularly in the vegetation surface microlayer will have a less direct relationship to possible mineral sources because there are other factors, in addition to the chemistry of the secondary environment, which influence transport of metals to leaf surfaces. These include availability of metals for absorption by root systems and varying response of different plant species to different metals. Availability of metals will depend on the soil chemistry, overburden drainage and, utimately, geology. Thus, element distribution patterns in the vegetation surface microlayer could reflect metals derived from exposed mineralization weathering in situ, or broad hydromorphic halos displaced some distance from mineralized source rock. In the following discussion, particular emphasis will be placed on the relationship between the multi-element variations described in the previous section, geology, and observable variations of the secondary environment.

Marathon Area

The most prominent feature of the airborne SURTRACE geochemistry is the marked enhancement of Ca,Sr,V, and Ti over the gabbroic and syenitic rocks forming the Coldwell complex. Smoothed Ca levels demonstrate the striking association with geology, and the contour for the mean plus 1.5 standard deviations parallels the gabbro-metavolcanic contact. Sr and V also increase in forest litter samples and vegetation leachates over the gabbro, confirming that the SURTRACE patterns do reflect underlying geological variations. However, the Ca content of forest litter is greatest over the area of glaciolacustrine clay to the northeast and this trend is not reflected by a similar increase of vegetation microlayer Ca. The absence of high Ca in the microlayer of this area is as yet unexplained.

Although increased microlayer Ca levels occur above the gabbro, the greatest abundance corresponds to the syenitic rocks where Ca outlines a roughly arcuate pattern enclosing the southwest corner of the survey area. This increase of Ca in the microlayer is in contrast to the lower absolute Ca content of the syenite compared to the gabbro. The syenite is deeply weathered and microprobe studies have determined that, although the total Ca content decreases from gabbro to syenite, the Ca content of olivine increases (Whittaker 1978). Also, the Ca distribution pattern generally reflects an area of high relief where there is almost continuous outcrop. A thicker cover of surficial material may explain the low Ca levels in the southwest part of the survey area.

The spatial distribution of trace elements (Cu,Ni,Zn,Cr) generally does not follow that of the major elements, which is most likely due to the different interaction of these metals with the metabolism of plants, and the less homogenous concentration of metals in bedrock. Ore-related elements (Cu,Ni,Cr,Ti,Fe) describe two basically different airborne SURTRACE anomaly patterns over the survey area. Strong multi-element anomalies (Nos.7,8,37,38; Chart A, back pocket) parallel to flight-line directions can be explained by the memory effect previously described for both sampling and analytical systems. These can easily be identified by orientation and by the strong enhancement of most minor and trace metals. Prominent anomalies also extend across several flight lines and these have been described in the previous section.

There is a significant Cu,Ni,Cr,Fe,Mn,Ti,V anomaly (No.19) close to the Anaconda Canada Exploration Limited occurrence and the multi-element signature suggests that it is related to the mineralization along the gabbro-volcanic contact. Anomalies 23 and 24 are also parallel to the contact and could reflect smaller sulphide concentrations in the gabbro. The small Cu.Ni anomalies 16,17,28,30, and 31 are probably due to small sulphide occurrences distributed along the contact. Several anomalies are associated with prominent topographic features or drainage channels and are orientated parallel to the direction of the features. Typical examples are anomalies 20,27,28, and 31 which are situated on visible drainages and can be explained by hydromorphic dispersion of metals into the stream channels and subsequent accumulation into the vegetation. Dispersion of elements from the area of the contact, downslope into the Pic River along a series of small streams visible on airphotographs, could also explain the very prominent Cu-Ni-Fe-Mn zone number 11. The reason for the displacement of the Ca contour towards the Pic River immediately north of the Anaconda Canada Exploration Limited occurrence is unknown, particularly as there is a prominent valley between the geological contact and the contour. Similarly the arcuate shaped Cu.Ni anomaly 18 cannot be explained in terms of the mapped geology and known distribution of mineral occurrences.

In the southern part of the survey area, there are several significant anomalies which extend across several flight lines and have strong multi-element associations. The Cu.Ni anomaly 33 corresponds to outcrop along a ridge crest and could reflect local variation of bedrock chemistry complimented by greater availability of elements for concentration into the microlayer. Anomalies 35 and 41 are essentially Cu enrichments in the microlayer and occur over prominent drainage channels. A similar environment is present in the case of anomalies 36 and 39. Possibly the most interesting and apparently unexplained features are the high contrast multi-element anomalies 40 and 42 which occur in an area underlain by overburden-covered syenite. Both anomalies are oriented parallel to airborne magnetic contours and therefore appear to reflect geological structure. One possible explanation for these zones is the presence of weakly mineralized dykes.

On the north side of the Pic River in the area dominated by glacial deposits are a number of small Cu and Cu.Ni anomalies (Nos.5,6,7,12,13), several of which correspond to drainage channels. Two, however, (Nos.10,14) do not reflect variation in the secondary environment and could possibly be related to variation in mineralogy of the surficial deposits.

The prominent Cu-Zn-Ni anomalies (Nos.1,3) occur at the edge of the surveyed area and have a general north-south trend. Association of higher Zn values with other trace elements suggests that the source has a character different than SURTRACE anomalies formed over the gabbro-syenite rocks. Small copper-bearing mineral occurrences have been reported in felsic volcanic rocks outcropping along the northern edge of the survey area, although the exact location is not documented. The anomalies could reflect this mineralization or the hydromorphic dispersion patterns associated with weathering of sulphides. Geology of this part of the survey area is complex and the rocks have undergone several phases of folding. Consequently, it is difficult to relate the anomalies to known geological trends or structures.

Marshall Lake Area

The most significant SURTRACE feature of the Marshall Lake survey area is the broad zone of Mg,Al,Ca, and Si enrichment with associated high Cu,Zn,Pb,Fe,Mn, and Ba values to the south of Gripp Lake and enclosing the Teck Corporation occurrences. The general shape of the major element pattern and particularly the northwest lobe follows airborne magnetic contours (O.G.S. Aeromagnetic Maps P.1588,P.1589,P.1593,P.1594) indicating that the element variations have some relationship to geology. One possible explanation for the size and shape of the major element anomaly is that the metals reflect wallrock alteration associated with the massive sulphide bodies. Increased water extractable Ca,K and Mg concentrations have been found in felsic rocks hosting the Heath Steele Mines Limited sulphide deposit in New Brunswick. The alteration halo surrounding the deposit could be detected several hundred meters beyond the sulphide mineralization (Goodfellow and Wahl 1976). A similar hydrothermal alteration halo may be associated with the sulphide mineralization forming the Teck Corporation occurrence and is reflected by the greater abundance of Ca,Al and Mg in the rock, soil and, ultimately, in the vegetation microlayer. The predominantly poplar and white birch timber stands throughout the area of the anomaly could reflect favourable growth conditions created by more alkaline soil due to the Ca-Mg accumulation, and also by more mature soil development. However, no rock alteration studies have been documented to confirm the relationship between the microlayer and rock geochemical patterns.

In addition to the reported sulphide mineral occurrences documented in the survey area, there are many smaller showings scattered throughout the region. A high proportion of the low contrast, small Cu and Zn SURTRACE anomalies probably reflect the presence of the widely distributed mineralization, and, for this reason, discussion is focused on the larger, more persistent trace element patterns. Within the broad zone of Ca,Al,Si enrichment, there are several clear relationships between outcropping base metal sulphides and Cu.Zn anomalies. Extremely high Cu.Zn product contrast (anomaly No.22) occurs over one sulphide showing. Element abundances decrease to the southwest and could reflect glacial smearing of material, or the presence of a hydromorphic dispersion pattern formed in the adjacent swampy stream channel. Anomaly 24 encloses a volcanic center and is closely associated with a mineral occurrence on the shore of Gripp Lake. Transport of weakly mineralized groundwater along faults, and the subsequent increased metal absorption by trees growing in the immediate area could explain the orientation of several anomalies such as Nos. 23 and 27, parallel to fault structures. Other SURTRACE anomalies within the region of the Teck Corporation occurrence appear to reflect poorly drained environments, for example, anomaly 21 which is situated on the margin of the Gripp River. A similar source of secondary metal enrichment could explain the northern part of anomaly 22. Lower Ca and Zn values, however, reflect a southern extension of this zone which covers an area of sporadic outcrop. In the extreme south of the Ca-Al enriched zone is one east-west trending Cu.Zn anomaly that does not have an apparent relationship to either mineralization or variation of secondary environment. Although no high contrast Cu.Zn patterns are indicated over the central part of the Teck Corporation showing, element levels are generally enhanced throughout the area.

Detailed examination of the character and geochemistry of the "Main" (Billiton Canada Limited) sulphide showing has demonstrated that narrow, high contrast soil zinc anomalies occur directly over the exposed sulphide mineralization, reflecting limited dispersion from the source. The corresponding SURTRACE samples are relatively low in Cu and Zn. Increased SURTRACE Cu,Zn and Pb levels do occur over thicker overburden corresponding to the esker north of the "Main" sulphide zone. A fundamental difference between the character of the SURTRACE Cu.Zn patterns over the Teck Corporation and "Main" sulphide zones can be explained by variation in the maturity of soil and forest cover. Almost continuous outcrop supporting black spruce growth and intersected by swamp is typical of the area surrounding the "Main" zone, compared to deeper, more mature soil development supporting poplar-white spruce cover in the region of the Teck Corporation zone. Due to the very thin soil development around the "Main" zone, migration of elements from weathering sulphides into root systems will be suppressed and accumulation of metals in the vegetation microlayer decreased. Despite the absence of a significant airborne geochemical anomaly over the "Main" zone, there is a subdued Cu enchancement to the south (anomaly 13) which corresponds to a swamp and may reflect secondary enrichment of copper from smaller sulphide occurrences. This anomaly also falls on a northeast-trending fault on which lies the small, high contrast Cu.Zn anomaly 14 and part of anomaly 12. Although the western edge of anomaly 12 is a strong flight-line-parallel feature, the two prominent peaks at the north and south ends correspond to faults and may reflect metal accumulation from groundwater.

Although two base metal occurrences are contained by anomaly 15, the limits of the SURTRACE Cu pattern only extend to the northern margin of the "Main" sulphide zone. An absence of detectable SURTRACE metal values in the vegetation microlayer directly over the "Main" zone can be explained by the very localized soil anomaly and the limited surface exposure of the sulphide mineralization. Higher SURTRACE Cu and Zn levels correspond to the area covered by an esker to the north of the "Main" zone. This enhancement could reflect greater porosity of the fluvioglacial deposit, permitting increased movement of weakly mineralized groundwater from concealed sulphide mineralization to the plant root systems. Although smaller SURTRACE anomalies (Nos.4,5) could be due to transported mineralized material in the esker, the most probable sources for anomaly 15 are small sulphide occurrences associated with the eastern volcanic centre.

The orientation of several of the SURTRACE anomalies in the southern part of the survey area follows the general trend of geological contacts and, therefore, would reflect minor, stratabound mineral occurrences. Although the western edge of anomaly 6 is strongly truncated by a multi-element, line-parallel anomaly, the eastern portion parallels the contact between metavolcanics and metasediments. Anomalies 9,30 and 31 appear to follow a linear trend which is roughly parallel to the metavolcanic-metasedimentary contact clearly visible on the airborne magnetic maps (O.G.S. Aeromagnetic Maps P.1588,P.1593,P.1594). Since small copper sulphide occurrences as well as iron formation are known to occur in the metasediments, it is conceivable that anomaly 9 reflects hydromorphic dispersion of metals from the contact zone. The Cu.Zn product values increase towards the east suggesting proximity of source. Anomalies 7 and 8 are in an area covered by extensive swamp and, therefore, have no apparent source

although concomitant increase of Ca,Al,Fe, and Mn, and the strong east-west orientation of anomaly 8 parallel to magentic contours would indicate a relationship to concealed geology. A similar interpretation can be made for anomaly 10 which is also parallel to a geological contact and also follows a prominent elongate magnetic high. However, the eastern edge of anomaly 10 is truncated by a strong multi-element line-parallel anomaly. In addition to the anomalies described above, there are several others (Nos.11,28,29,30) which cannot be adequately explained.

In the northern part of the survey area several anomalies have been identified of which the largest is number 1. The Cu.Zn products define a strong west-northwest trend which is parallel to the metasedimentary-metavolcanic contact and also follows magnetic contours. The orientation of this anomaly strongly suggests a relationship with underlying geology, particularly as minor copper sulphide mineralization is known to occur along the contact. A southerly extension from the principal zone of element enhancement follows a drainage channel and could reflect hydromorphic accumulation of elements. Both the southern lobe of anomaly 1 and the northern portion of anomaly 2 trend east-west, parallel to magnetic contours. This orientation suggests they may also reflect a concealed source in bedrock. The greatest Cu.Zn product contrast in anomaly 3 corresponds to exposed contact between gabbro and felsic volcanic rocks. Also, the general trend of this anomaly parallels magnetic contours suggesting a relationship to bedrock geology.

Interpretation of anomalies in the area to the west, underlain by extensive fluvioglacial sands, is complicated by the absence of outcrop and features which may explain the element patterns. Anomaly 17, for example, follows the magnetic contours which suggests a relationship with geology. Similar relationships can be observed in the cases of anomalies 18 and 19. The prominent fault which intersects anomaly 18 may be a secondary source for the metals associated with this enhancement. Anomalies 16 and 26 are unexplained.

CONCLUSIONS AND RECOMMENDATIONS IN THE SURVEY AREAS

Marathon Area

(1) In the Marathon area base metal sulphide occurrences hosted in gabbroic rocks confirm airborne SURTRACE copper and nickel anomalies. Anomaly contrast is improved using Cu.Ni products rather than raw, normalized element values and a prominent Cu-Ni-Cr anomaly is identified over part of the principal sulphide mineral zone.

(2) Major geological changes can be detected by the spatial distribution of several elements in the vegetation microlayer. In the Marathon area, Ca,Sr and V values are consistently higher over gabbro and syenite units of the Coldwell intrusive complex compared to levels over felsic volcanic rocks. Using an averaging technique to smooth the data, the contact between gabbro and the volcanic rocks is clearly defined by increased Ca abundances.

(3) Although the spatial distribution of the element patterns is confirmed by known mineralization and corresponds to geological variations, there are other SURTRACE anomalies which cannot be explained at this time. The development of criteria for efficiently interpreting data from conventional geochemical programs has occurred over a number of years, and development of similar methods, applicable to airborne SURTRACE data, will require further studies before the significance of many of the anomalies can be confidently established.

Marshall Lake Area

(1) Anomalous Cu and Zn values are located in the Marshall Lake area and are indicative of known mineralization in this area. There are airborne SURTRACE Cu anomalies flanking the "Main" (Billiton Canada Limited) sulphide zone. Subdued SURTRACE response in the immediate area of the "Main" sulphide zone can be explained by the relatively narrow width of the exposed base metal sulphides and the limited secondary dispersion due to the thin soil development.

(2) Strong Cu.Zn anomalies within a broad area of major element enhancement occur over the Teck Corporation occurrence in the Marshall Lake area in contrast to the subdued SURTRACE expression over the "Main" sulphide zone. The contrast and spatial consistency of multi-element patterns over the Teck sulphide zone may reflect greater availability of metals due to more mature soil development and variation in the vegetation. Higher concentrations of major elements could reflect a hydrothermal wall-rock alteration halo surrounding the sulphide mineralization.

Anomaly Characteristics Common to Both Areas

In both survey areas there are a number of anomalies which have no apparent relationship to known sulphide mineral occurrences. Possible explanations for these anomalies are:

(1) Many of these correspond to drainage channels or swamps and therefore could be explained by hydromorphic dispersion patterns shown by element enhancement in the vegetation microlayer.

(2) The similarity of orientation between several regional anomalies in the Marshall Lake area and the airborne magnetic contours strongly suggests that the SURTRACE patterns reflect local lithological variations in the underlying volcanic rocks.

(3) A number of strong multi-element SURTRACE anomalies are aligned parallel to flight lines and this lineation is thought to reflect a memory effect during the LASERTRACE analysis which, starting with a highly anomalous sample, may persist through several subsequent sample analyses. Although anomalies of this type can be misleading, they are readily distinguished from significant patterns, and their presence is a positive indication of anomalous metal concentrations in a survey area.

RECOMMENDATIONS

(1) Results of the present surveys have clearly demonstrated that broad geochemical patterns related to favourable geological environments for base metal sulphide mineralization can be detected using airborne SURTRACE sampling as a reconnaissance exploration technique. However, it is strongly recommended that airborne geophysical methods (magnetic, electromagnetic) be combined with the SURTRACE data to provide maximum discrimination between anomalies related to changes in the surface secondary environment, and those due to sulphide mineralization and other primary features of the bedrock.

(2) In addition to those SURTRACE anomalies which can be explained by variations of geology, secondary environment, or known mineral occurrences, there are a number of strong multi-element patterns which do not have an apparent source. Anomalies 1 and 40 in the Marathon area are in regions where there is no documented evidence of mineralization and further ground examination is recommended. In the Marshall Lake survey area, Anomalies 1 and 9 are parallel to airborne magnetic contours and geological contacts, suggesting possible linear zones of mineralization. Ground examination of these regions should be carried out to establish the source of the element enhancement. Rock and soil geochemistry should be conducted over the area of the Teck Corporation occurrences in the Marshall Lake area to establish if the large SURTRACE anomalies do reflect hydrothermal alteration patterns associated with the sulphide mineralization.

(3) Aside from directed studies aimed at refining criteria for identifying SURTRACE anomalies related to mineralization, further work is required on the processes governing the dispersion of elements from bedrock to the surface of vegetation. The unexpected but remarkably consistent behavior of Ca in the Marathon area, for example, is indicative of some fundamental process(es) governing element migration. Work in background (unmineralized) areas would provide necessary information on normal dispersion processes. Such information would permit confident use of SURTRACE as a basic mapping technique in support of conventional geology, as well as a prospecting system for use in the search for gross anomalies related to possible mineralization.

ADVANTAGES, APPLICATIONS, AND LIMITATIONS OF THE AIRBORNE SURTRACE TECHNIQUE

Advantages

(1) The method provides a rapid, cost-effective geochemical exploration approach to forest-covered areas where conventional prospecting techniques are costly and time-consuming due to difficult access and ground conditions.

(2) Multi-element analysis of SURTRACE samples by the LASERTRACE system can be carried out at a low cost compared to conventional techniques.

Although the geochemical results cannot directly indicate the grade of the mineralization, the multi-element information, when integrated with geological and geophysical data, can outline favourable environments.

Applications

(1) It is envisaged that SURTRACE could become an important exploration method in the Canadian Shield when used as a follow-up technique to airborne geophysical (electromagnetic and magnetic) surveys. The proposed method of operation would be to sample EM conductors for base metals and then establish priorities for further exploration.

Limitations

(1) One problem is that of maintaining uniform aircraft altitude during sampling, especially in rugged terrain and when there are strong turbulent winds. However, this problem can be overcome provided that the pilot is capable of handling the aircraft under the survey conditions, and the aircraft has sufficient power to correct for sudden changes of vertical movement.

(2) Navigation can be difficult.

(3) Although dry conditions are essential for SURTRACE survey work, only a few hours of sun are required to dry leaf surfaces after rain before sampling can be carried out. More serious disruptions of survey operations are generally due to poor visibility or high winds which ground the aircraft.

(4) One common feature of airborne SURTRACE data is the alignment of anomalies parallel to flight lines. This lineation is thought to reflect a memory effect caused by incomplete backflushing of particles in the sampling system, and volatile condensation during the LASERTRACE analysis which, starting with a highly anomalous sample, may persist through several subsequent sample analyses. Although anomalies of this type can be misleading, they are readily distinguished from significant patterns. However, their presence is a positive indication of anomalous concentrations of metals in the survey area.

(5) Because these SURTRACE surveys represent the first conducted over extensively forested areas of North America, lack of practical experience means that the interpretation remains uncertain. Further work on processes of element migration from mineralized sources into the vegetation microlayer is required so that airborne SURTRACE distribution patterns can be more confidently explained. However, the relationship between airborne magnetic and SURTRACE geochemical data appears to confirm a strong component of primary control by geology on SURTRACE distribution patterns.

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Ministry of Natural Resources

Ontario

Ontario Geological Survey

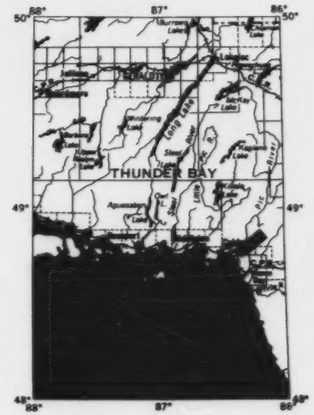
Geophysical-Geochemical Series

MARATHON

DISTRICT OF THUNDER BAY

CHART A
SURTRACE INTERPRETATION

Airborne Geochemical Survey



1 inch to 50 miles

N.T.S. Reference 42D/16

OGS-GSC Aeromagnetic Map: 2157G

OGS Geological Compilation Maps 2220, 2232.

LEGEND

Fligh line with sample position and numbers.

Ground sample stations and numbers.

231

Ministry of Natural Resources
Ontario

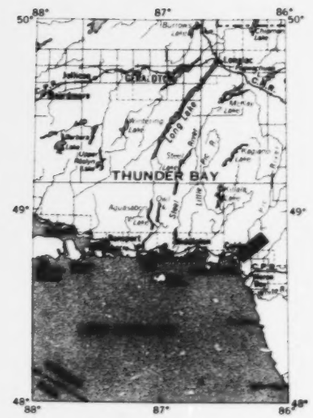
Ontario Geological Survey
Geophysical-Geochemical Series

MARATHON

DISTRICT OF THUNDER BAY

CHART B
SURTRACE COPPER

Airborne Geochemical Survey



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LEGEND

4 — Contours at standard deviation above the mean.

60 — Flight line with sample position and numbers.

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Ministry of Natural Resources

Ontario

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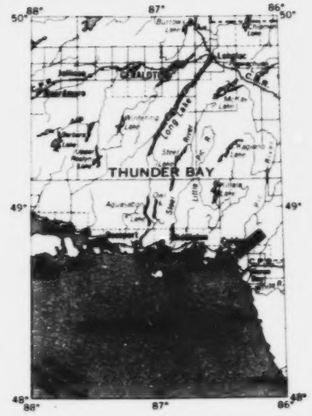
Geophysical-Geochemical Series

MARATHON

DISTRICT OF THUNDER BAY

CHART C
SURTRACE NICKEL

Airborne Geochemical Survey



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OGS Geological Compilation Maps 2220, 2232

LEGEND

4 — Contours at standard deviation above the mean.

808 — Flight line with sample position and numbers.

808 — Ground sample stations and numbers.

231

Ministry of Natural Resources

Ontario

Ontario Geological Survey

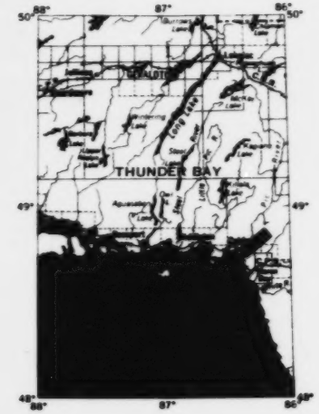
Geophysical-Geochemical Series

MARATHON

DISTRICT OF THUNDER BAY

CHART D
SURTRACE CALCIUM

Airborne Geochemical Survey



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OGS Geological Compilation Maps 2220, 2232

LEGEND

4 — Contours at standard deviation above the mean.

60 — Flight line with sample position and numbers.

Ministry of Natural Resources
Ontario

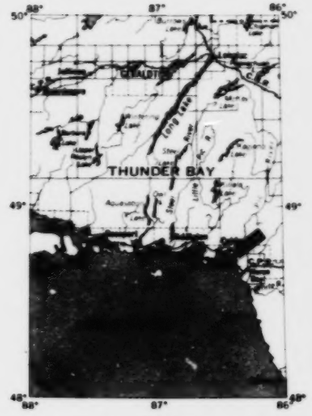
Ontario Geological Survey
Geophysical-Geochemical Series

MARATHON

DISTRICT OF THUNDER BAY

CHART E
SURTRACE STRONTIUM

Airborne Geochemical Survey



1 inch to 50 miles

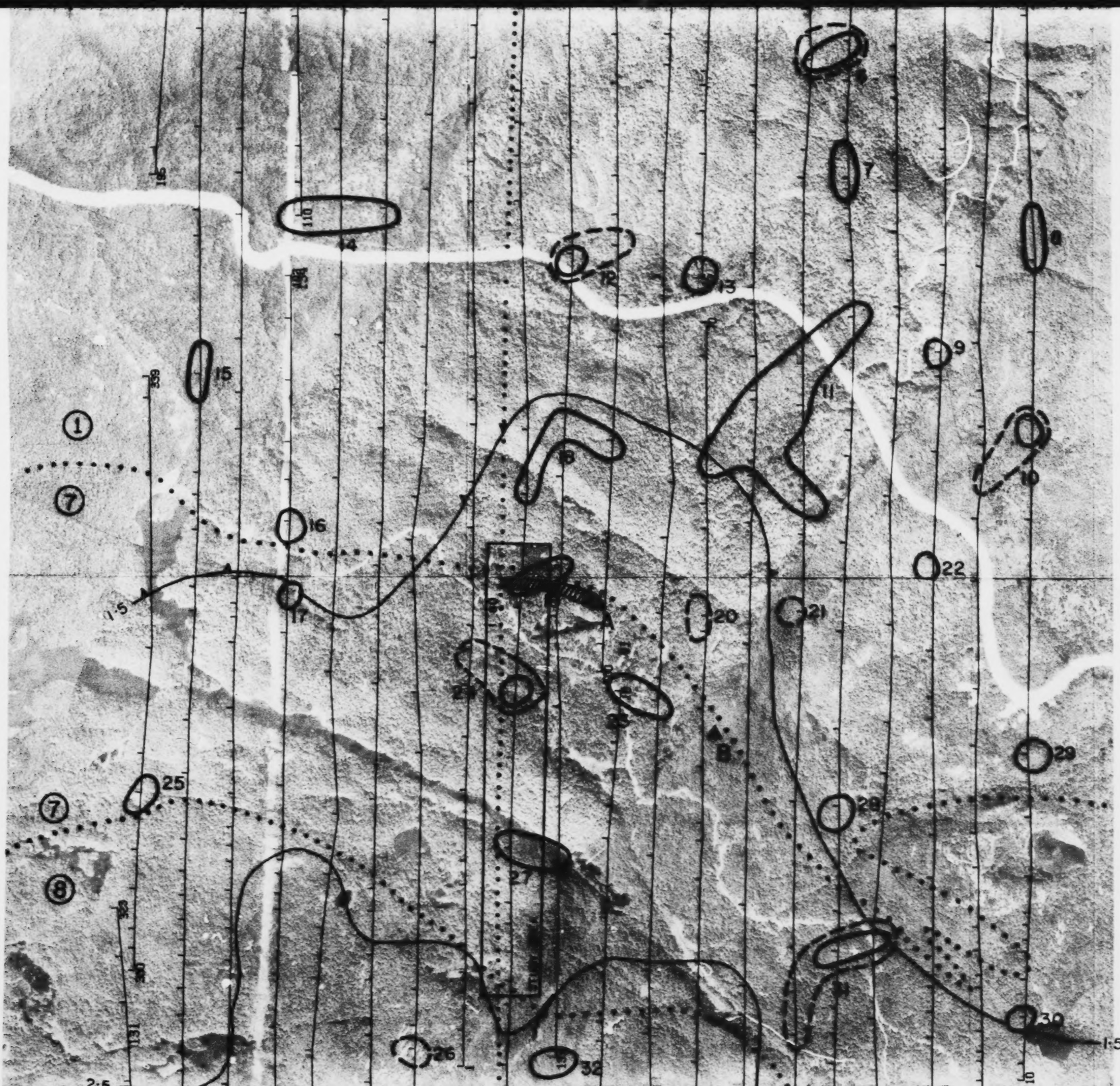
N.T.S. Reference 42D/16
OGS-GSC Aeromagnetic Map: 2157G
OGS Geological Compilation Maps 2220, 2232

LEGEND

4 — Contours at standard deviation above the mean.

60 — Flight line with sample position and numbers.

60 — Ground sample stations and



LEGEND

- Fligh line with sample position and numbers.
- Ground sample stations and numbers.
- Outline of detailed study area.
- Element anomalies outlined by Cu,Ni products greater than mean plus 2.5 standard deviations.
- Cu and/or Ni and/or Zn values greater than mean plus 2.5 standard deviations.
- Contour for smoothed Ca values greater than mean plus 1.5 standard deviations.
- Contour for smoothed Ca values greater than mean plus 2.5 standard deviations.
- Geological contact.
- A Sulphide mineral occurrence.
- (8) Syenite.
- (7) Gabbro.
- (1) Basic-Acid Archean metavolcanic rocks

DESCRIPTIVE NOTES

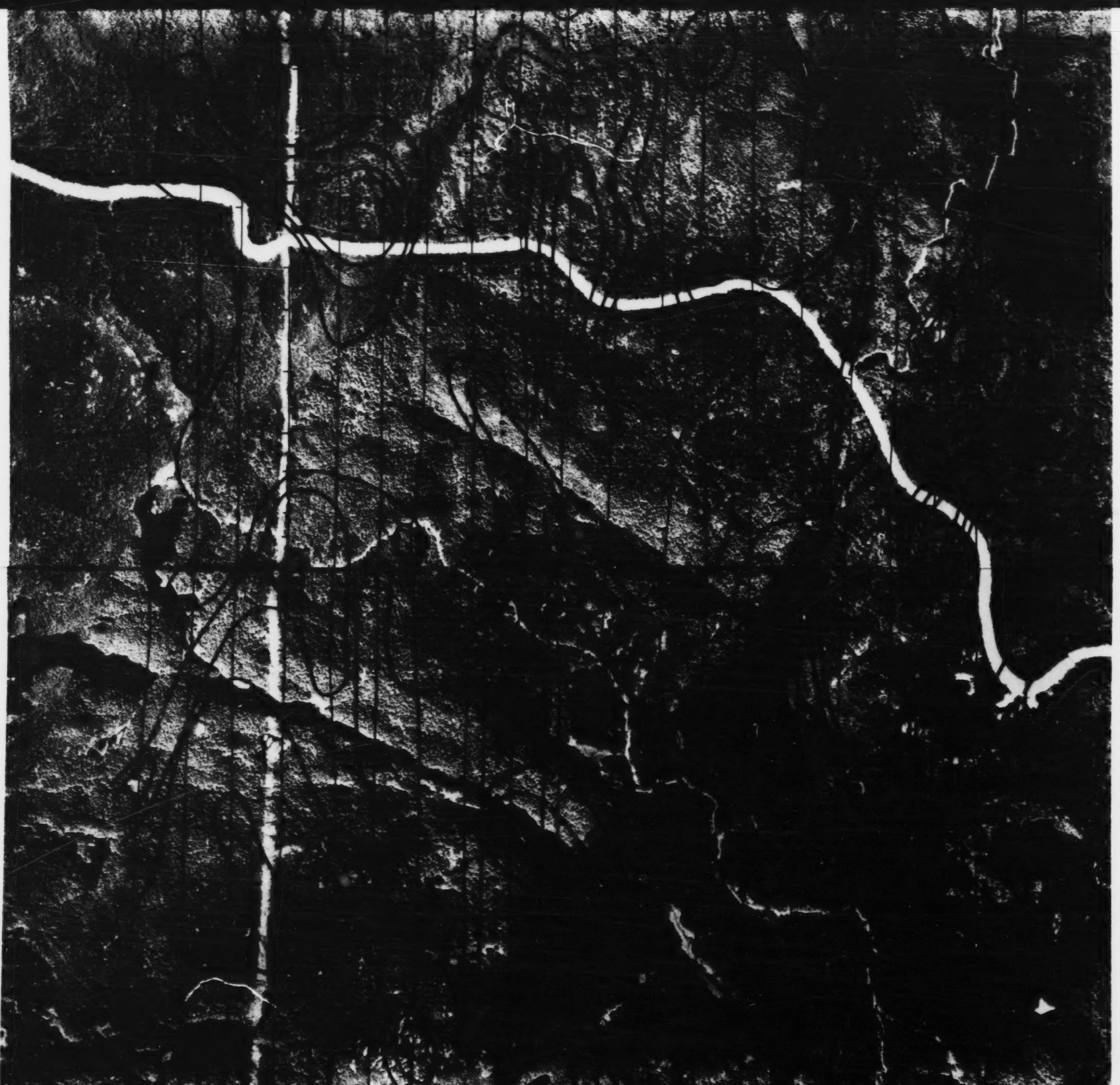
Samples of particulate matter are collected from the vegetation surface microlayer by the Barringer SURTRACE[R] system and stored on an AIRTRACE[R] Mk. III tape deck mounted in a helicopter. The samples are later analyzed for up to 24 elements by the Barringer LASERTRACE[R] laser pyrophysics technique.

Geochemical patterns are portrayed in map form using normalized analytical data for individual elements. Anomalies are selected by inspection of hand contoured element maps on which variability is displayed in forms of standard deviation above the mean.

The survey was flown in June 1979 using an Alouette II helicopter.

Data Compilation, interpretation and drafting was done by Barringer Research Limited, 304 Carlingview Drive, Rexdale, Ontario during June-November 1979.

Mosaic Base: The semi-controlled mosaic base was prepared by Barringer Magenta Limited from Forest Resources Inventory maps and photographs available from the Ontario Ministry of Nat-



4 Contours at standard deviation above the mean.

80 Flight line with sample position and numbers.

80 Ground sample stations and numbers.

Outline of detailed study area.

DESCRIPTIVE NOTES

Samples of particulate matter are collected from the vegetation surface microlayer by the Barringer SURTRACE® system and stored on an AIRTRACE® Mk. III tape deck mounted in a helicopter. The samples are later analyzed for up to 24 elements by the Barringer LASERTRACE® laser pyrophysics technique.

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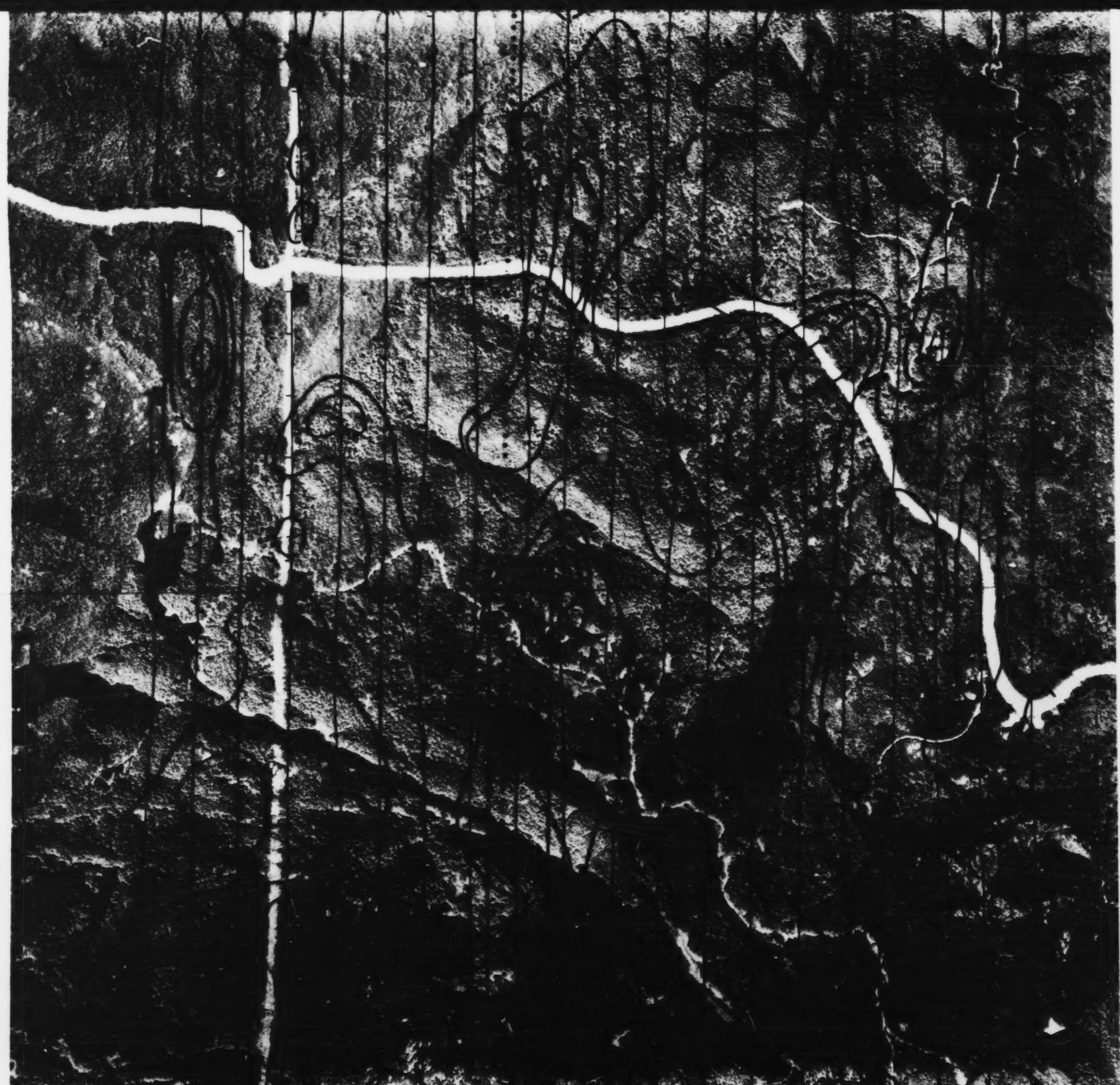
Funding for this project was received from the Ontario Ministry of Northern Affairs.



LEGEND

4 — Contours at standard deviation above the mean.

80 — Flight line with sample position and numbers.

808 — Ground sample stations and numbers.

Outline of detailed study area.

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Mosaic Base: The semi-controlled mosaic base was prepared by Barringer Magenta Limited from Forest Resources Inventory maps and photographs available from the Ontario Ministry of Natural Resources.

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Funding for this project was received from the Ontario Ministry of Northern Affairs.

LEGEND

4 — Contours at standard deviation above the mean.

68 — Flight line with sample position and numbers.

808 — Ground sample stations and numbers.

Outline of detailed study area.

DESCRIPTIVE NOTES

Samples of particulate matter are collected from the vegetation surface microlayer by the Barringer SURTRACE® system and stored on an AIRTRACE® Mk. III tape deck mounted in a helicopter. The samples are later analyzed for up to 24 elements by the Barringer LASERTRACE® laser pyrophysics technique.

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above the mean.

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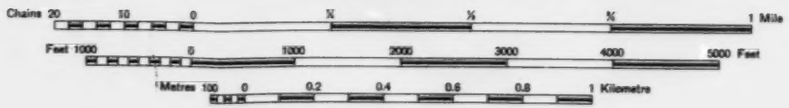
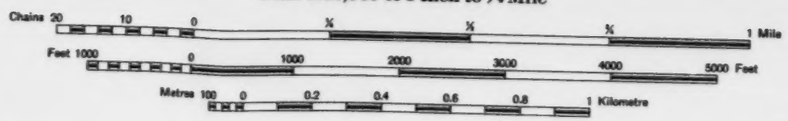
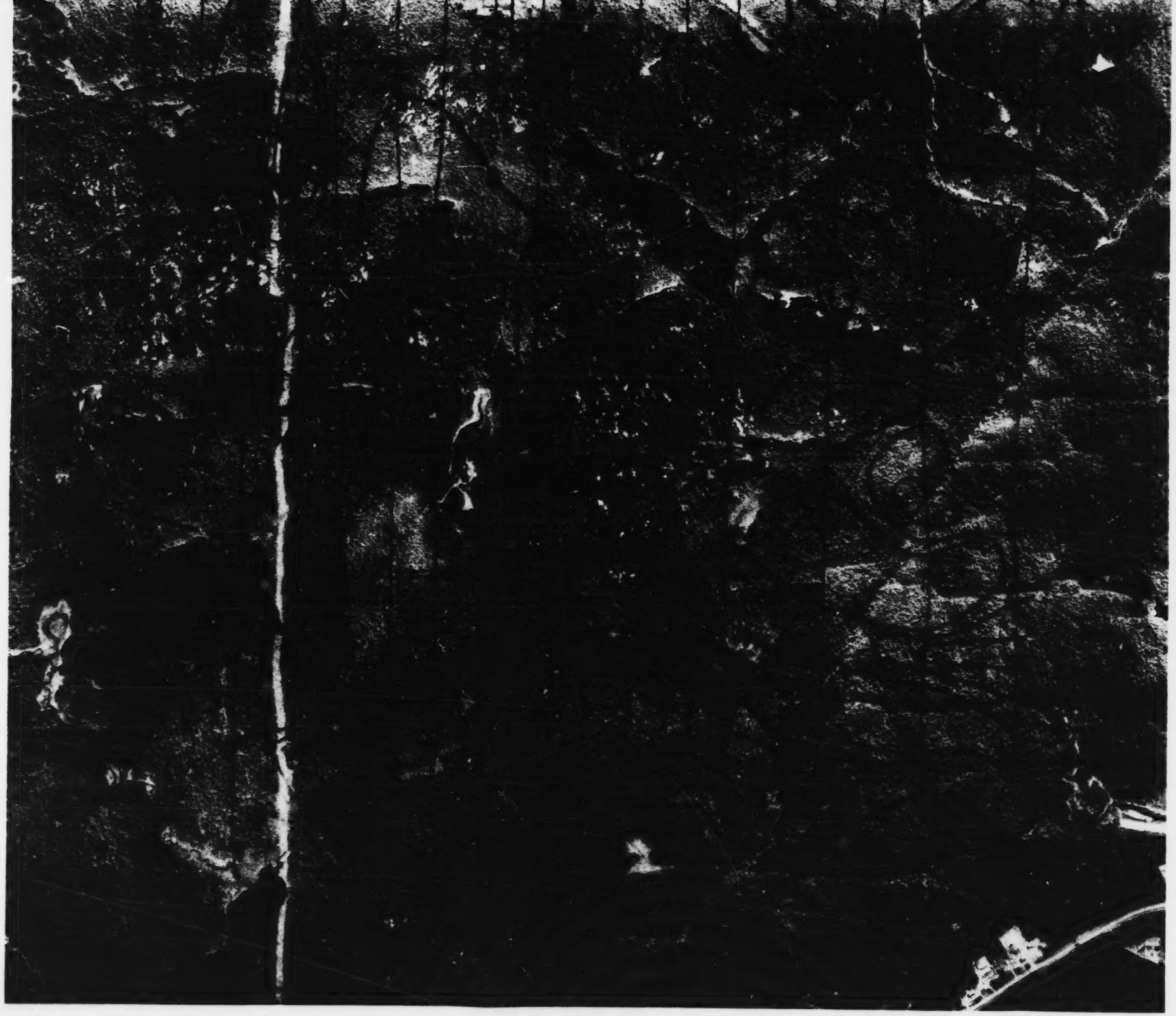
Scale 1:15,840 or 1 Inch to ¼ Mile



Scale 1:15,840 or 1 Inch to ¼ Mile





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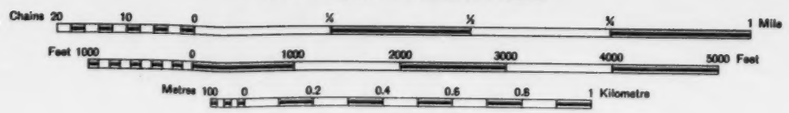
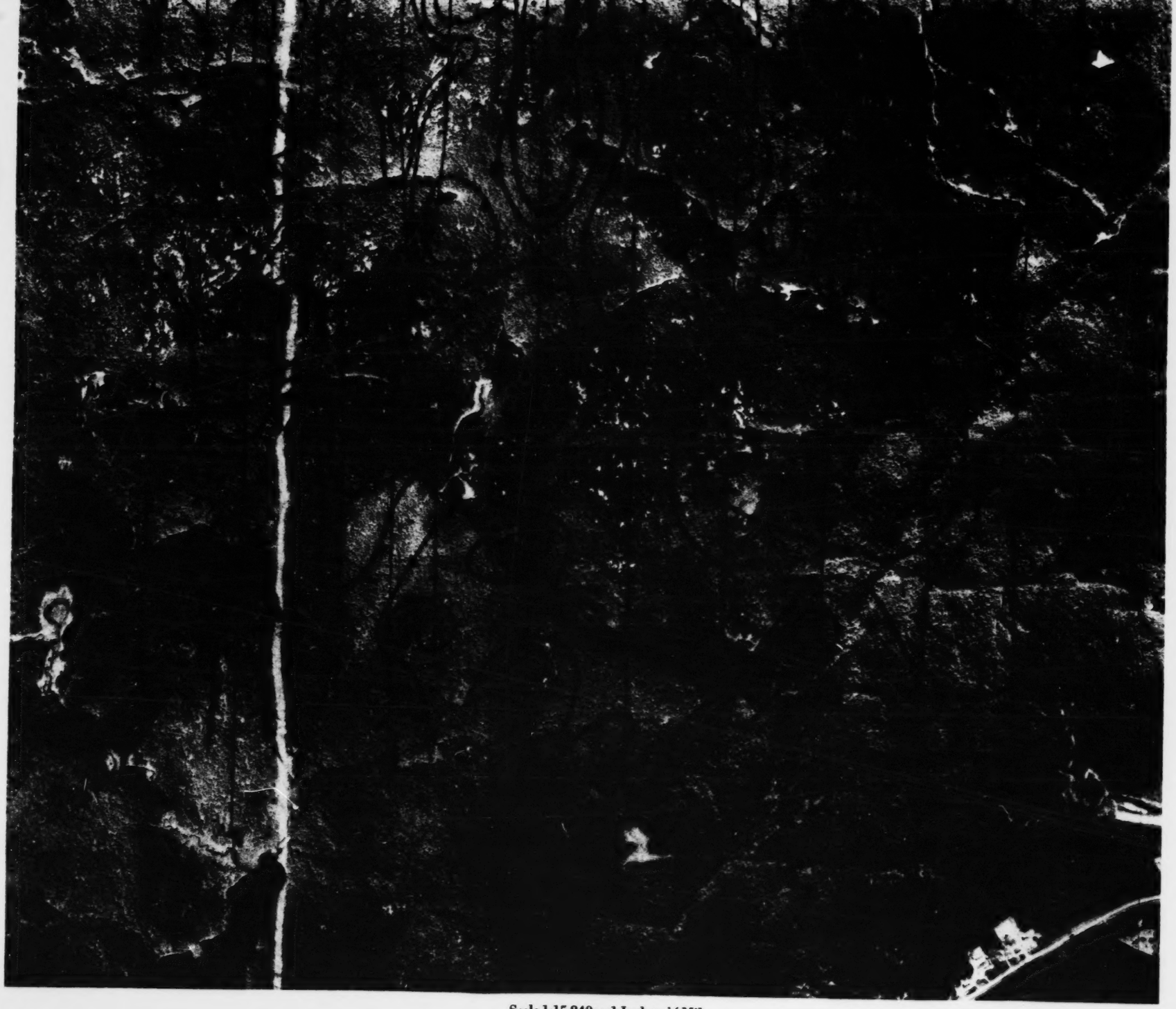
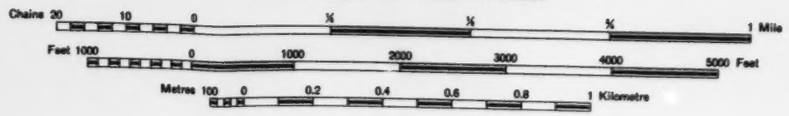
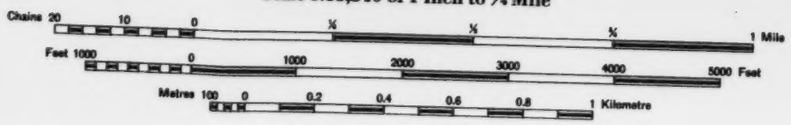




Scale 1:15,840 or 1 Inch to ¼ Mile



Scale 1:15,840 or 1 Inch to ¼ Mile



Ministry of Natural Resources

Ontario

Ontario Geological Survey

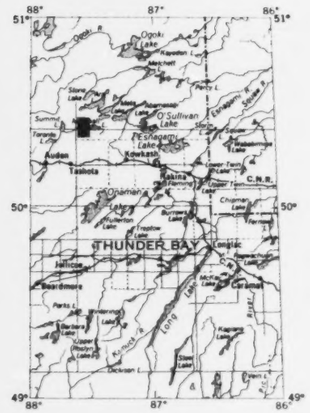
Geophysical-Geochemical Series

MARSHALL LAKE

DISTRICT OF THUNDER BAY

CHART F
SURTRACE INTERPRETATION

Airborne Geochemical Survey



1 inch to 50 miles

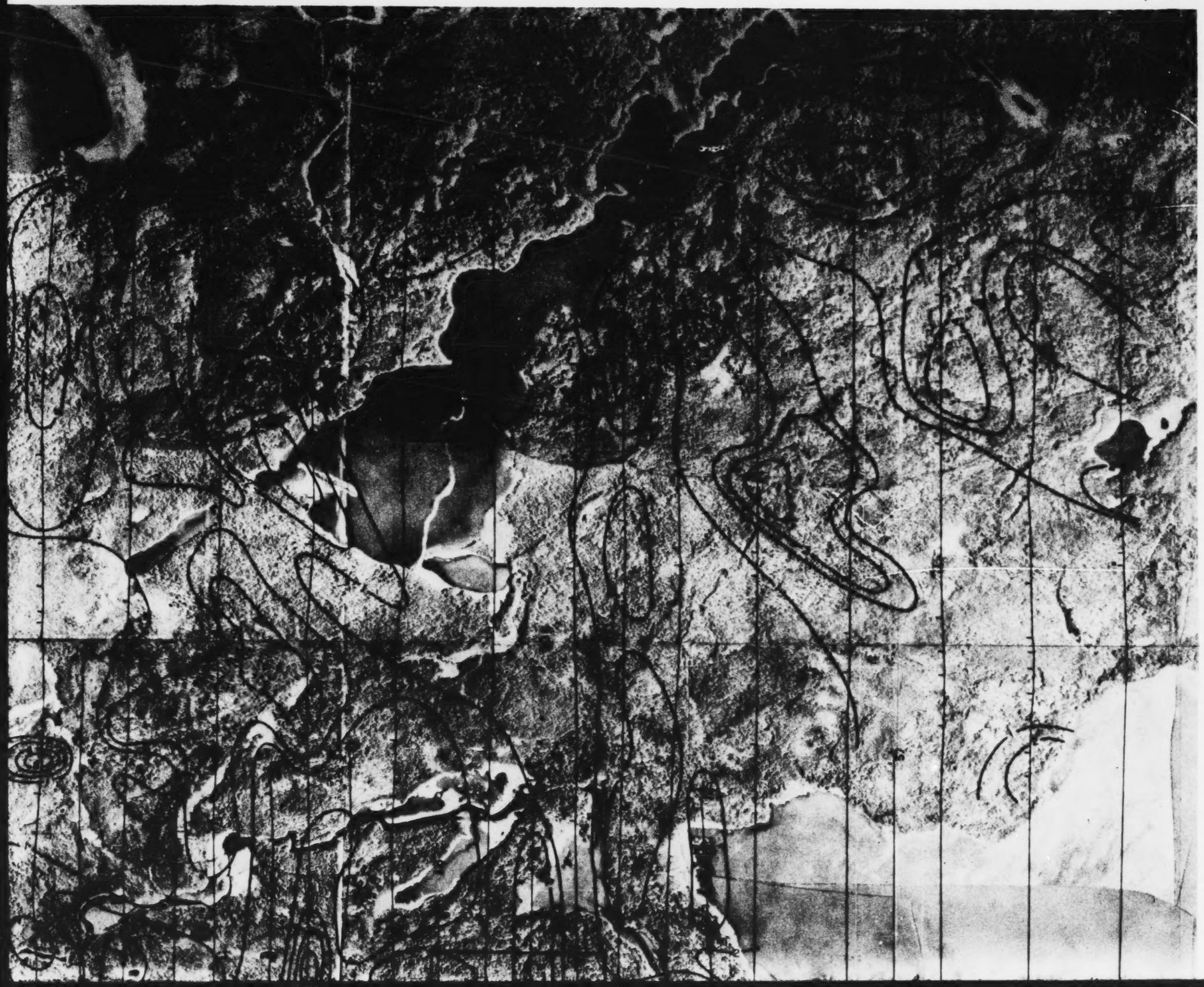
N.T.S. Reference 42L/5, 42L/6

OGS Aeromagnetic Maps: P1588 P1589, P1593, P1594

OGS Geological Compilation Map: 2102

LEGEND

- 80 — Flight line with sample position and numbers.
- 808 — Ground sample stations and numbers.
- Outline of detailed study area.



Ministry of Natural Resources

Ontario

Ontario Geological Survey

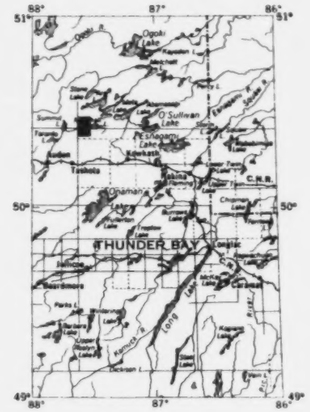
Geophysical-Geochemical Series

MARSHALL LAKE

DISTRICT OF THUNDER BAY

CHART G
SURTRACE COPPER

Airborne Geochemical Survey



1 inch to 50 miles

N.T.S. Reference 42L/5, 42L/6

OGS Aeromagnetic Maps: P1588 P1589, P1593, P1594

OGS Geological Compilation Map: 2102

LEGEND

4 — Contours at standard deviation above the mean.

80 — Flight line with sample position and numbers.

80 — Ground sample stations and numbers.

Outline of detailed study area.

Ministry of Natural Resources
Ontario

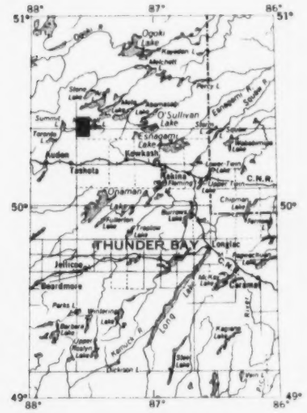
Ontario Geological Survey
Geophysical-Geochemical Series

MARSHALL LAKE

DISTRICT OF THUNDER BAY

CHART H
SURTRACE ZINC

Airborne Geochemical Survey



1 inch to 50 miles

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OGS Aeromagnetic Maps: P1588 P1589, P1593, P1594
OGS Geological Compilation Map: 2102

LEGEND

4 — Contours at standard deviation above the mean.

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Outline of detailed study area.

Cu

Cu, Zn

VOLCANIC CENTRE

24

TECK OCCURRENCE

MAIN OCCURRENCE

Zn Ag

14

23

21

22

Cu Zn

Cu

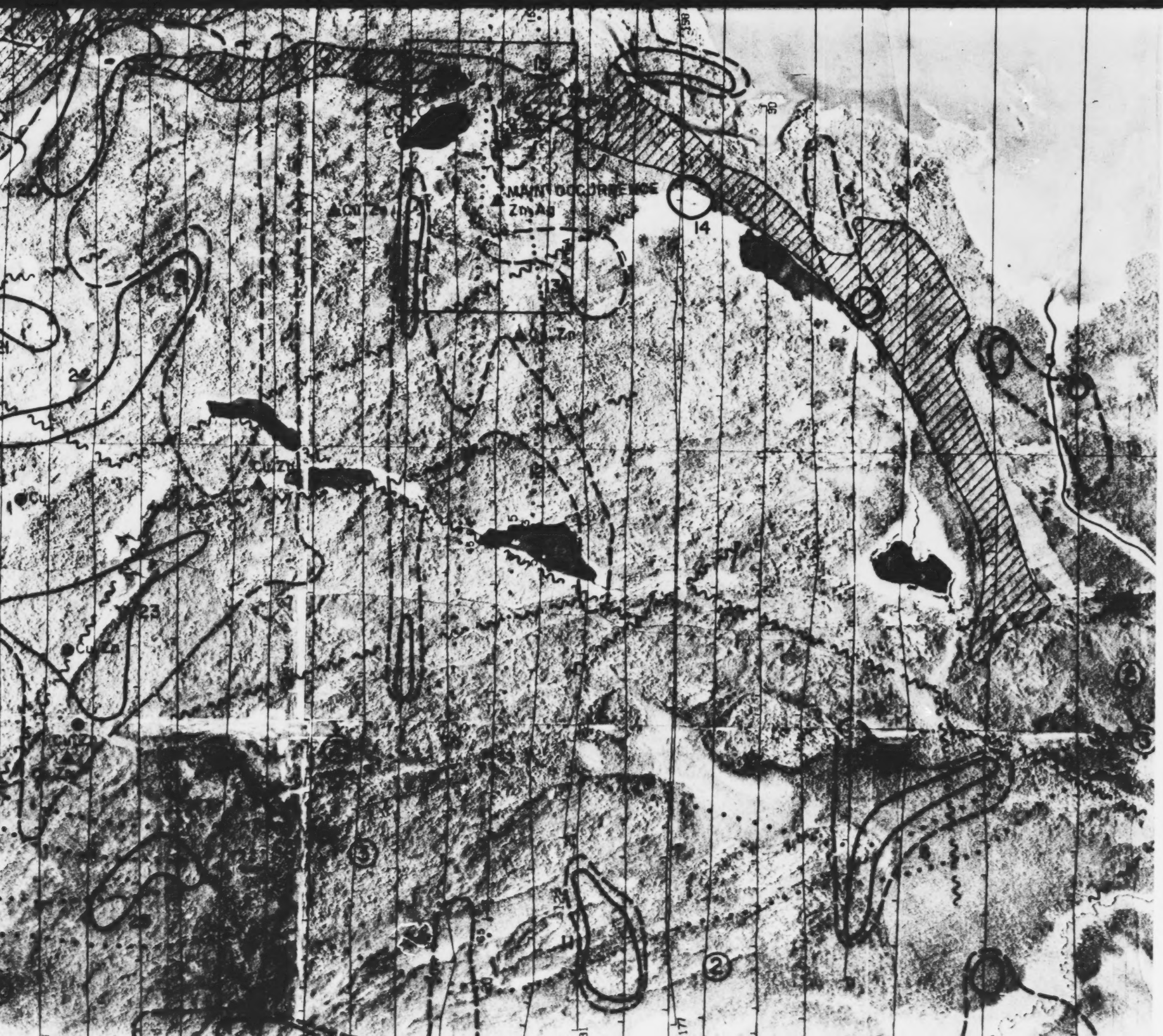
Zn

Ag

Pb

2

3



Ground sample stations and numbers.

Outline of detailed study area.

Principle Cu-Zn anomalies defined by Cu-Zn product values greater than mean plus 2.5 standard deviation. Number refers to description in text.

Cu and/or Zn values greater than mean plus 1.5 standard deviations with significant multi-element association.

Geological contact.

Felsic to intermediate metavolcanics.

Metavolcanics and metasediments

Gabbro.

Approximate limit of sandy outwash.

Prominent fault.

▲Cu Prominent mineral occurrence.

●Cu,Zn Minor mineral occurrence.

Esker.

DESCRIPTIVE NOTES

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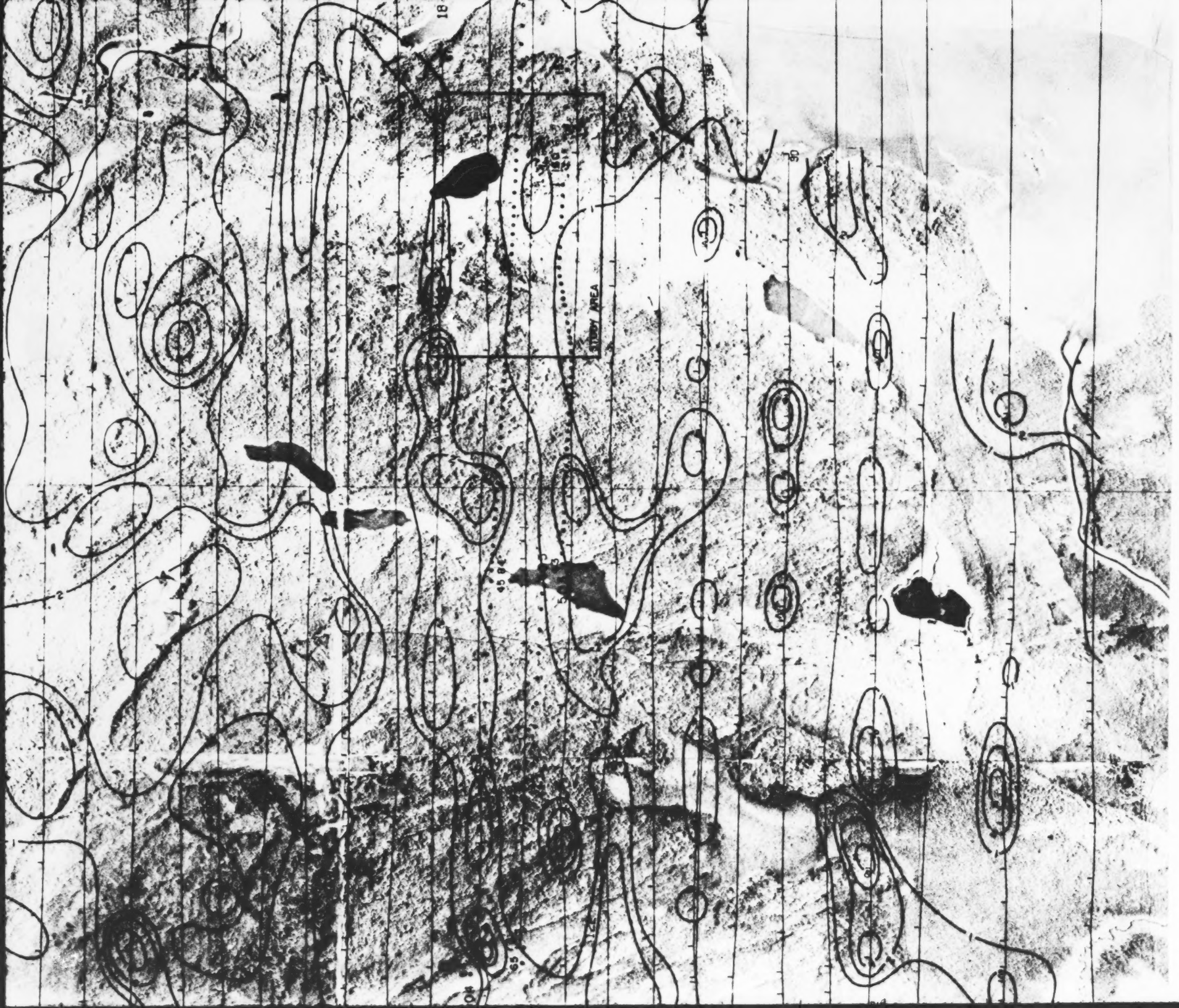

Ground sample stations and numbers.

Outline of detailed study area.

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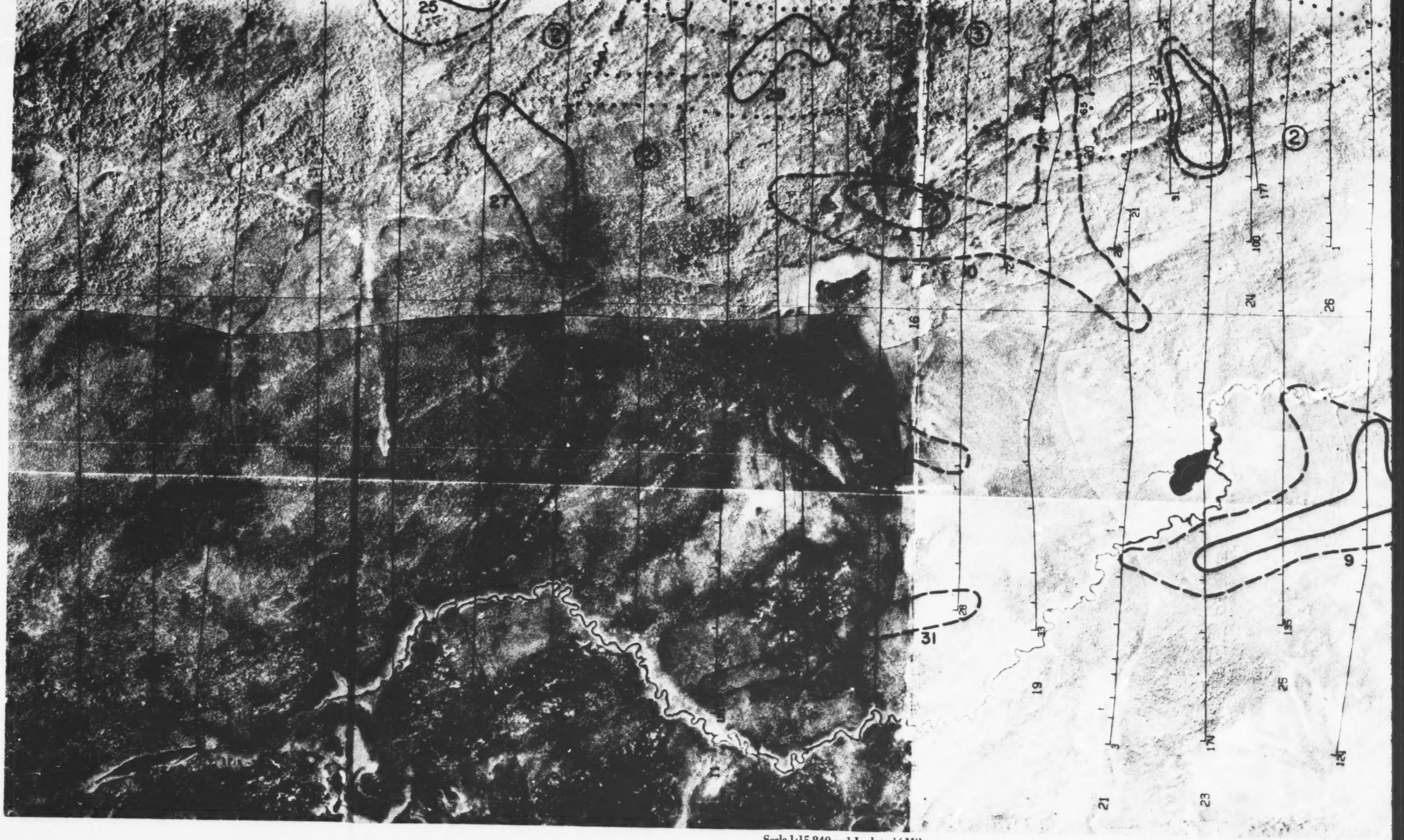
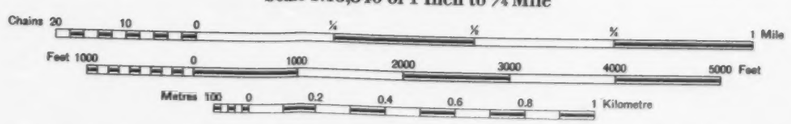


Scale 1:15,840 or 1 Inch to ¼ Mile



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IRON FORMATION

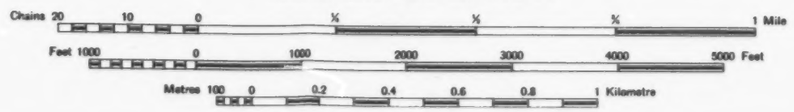
Scale 1:15,840 or 1 Inch to ¼ Mile

Chains 20 10 0 ¼ ¼ ¼ 1 Mile

Feet 1000 0 1000 2000 3000 4000 5000 Feet

Metres 100 0 0.2 0.4 0.6 0.8 1 Kilometre

Scale 1:15,840 or 1 Inch to ¼ Mile



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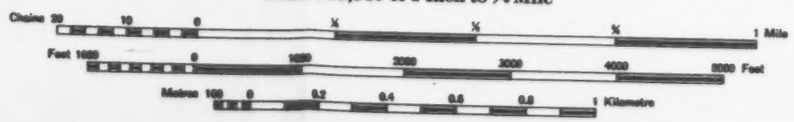
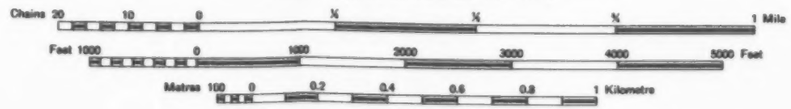
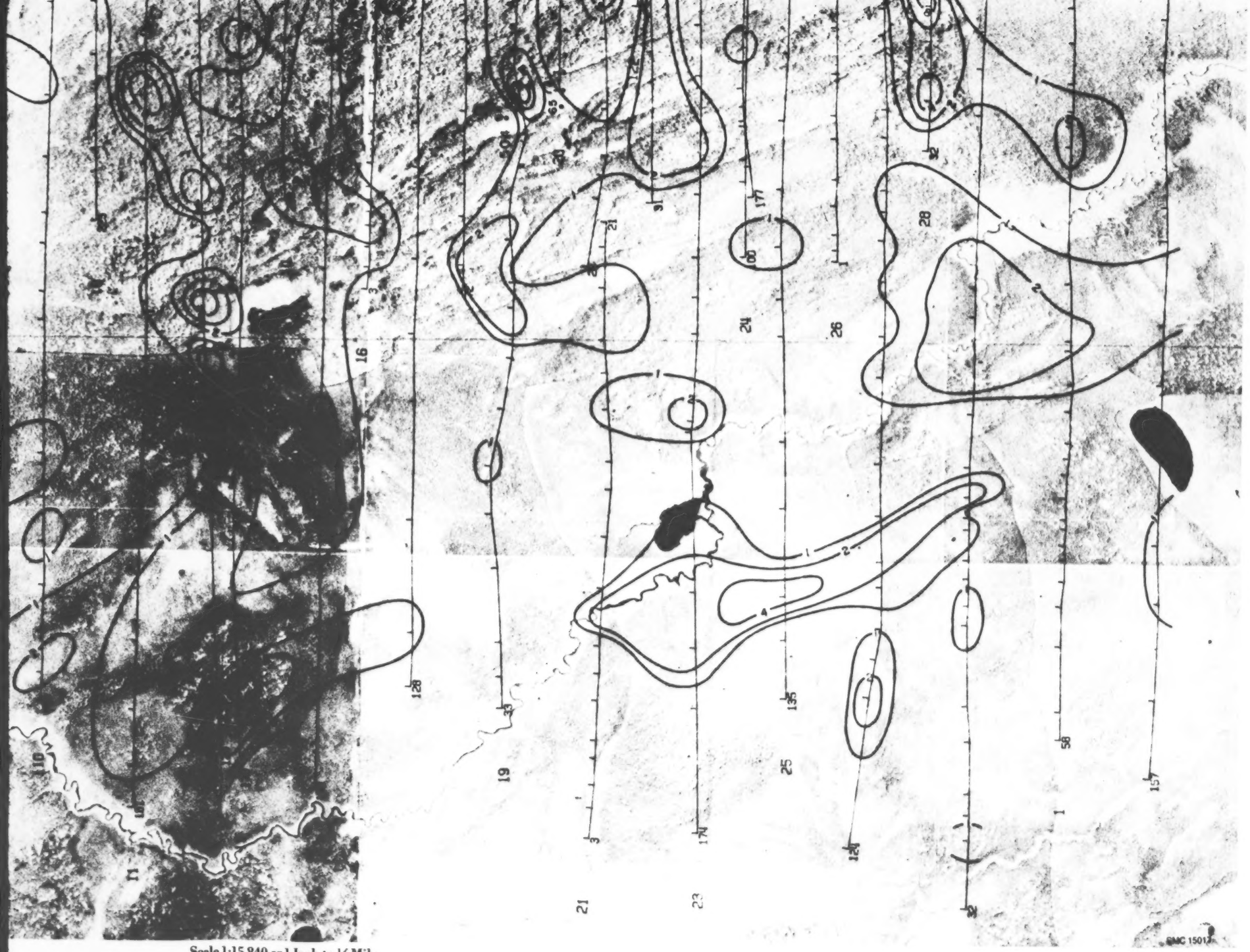


Scale 1:15,840 or 1 Inch to ¼ Mile





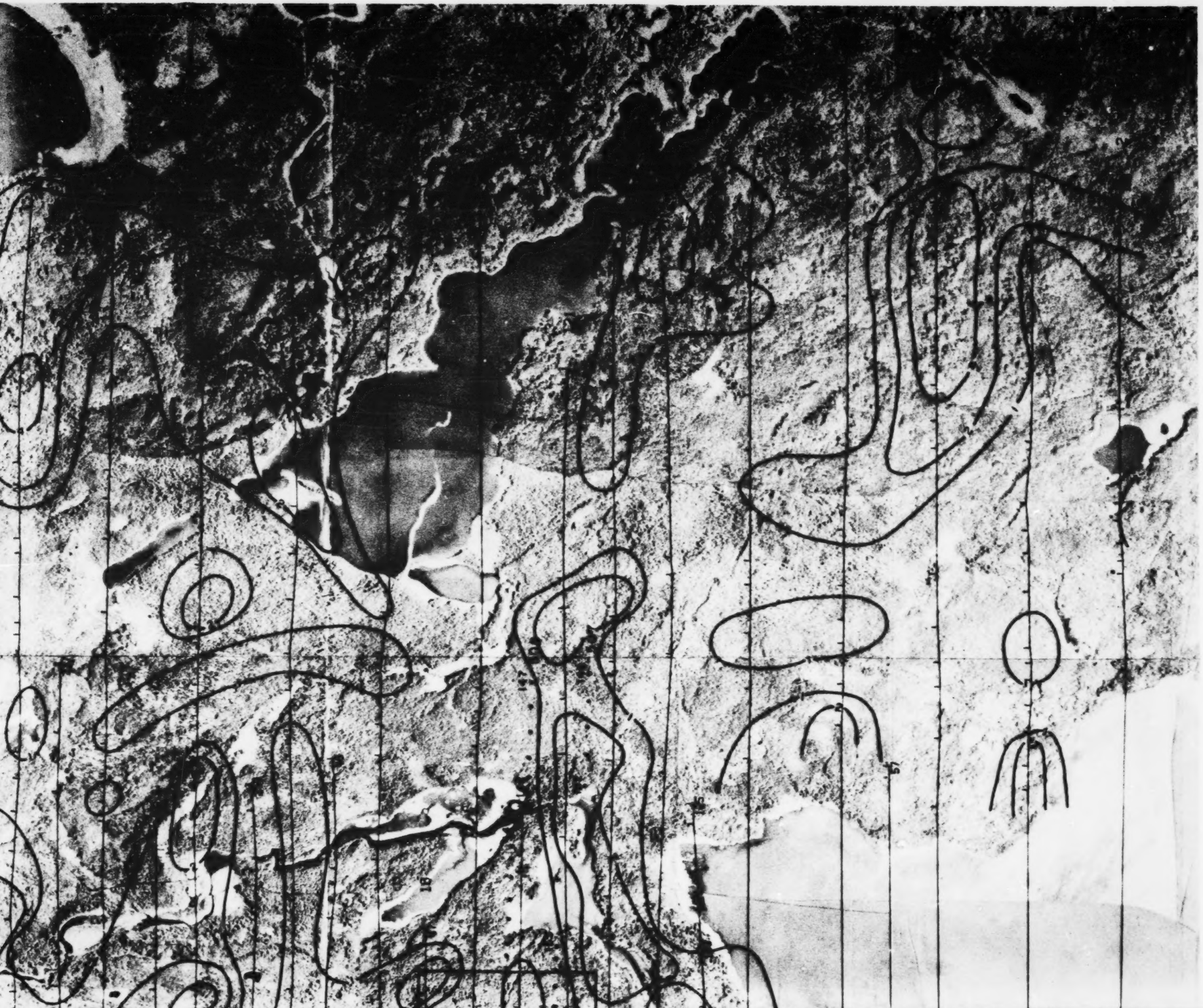
Scale 1:15,840 or 1 Inch to ¼ Mile

Chains 20 10 0 ¼ ½ ¾ 1 Mile

Feet 1000 0 1000 2000 3000 4000 5000 Feet

Metres 100 0 0.2 0.4 0.6 0.8 1 Kilometre

SMC 15012



Ministry of Natural Resources
Ontario

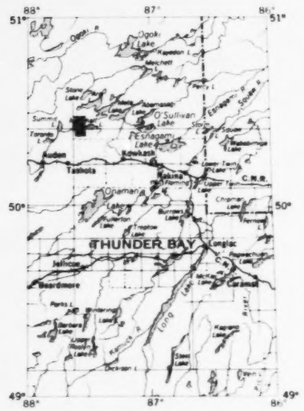
Ontario Geological Survey
Geophysical-Geochemical Series

MARSHALL LAKE

DISTRICT OF THUNDER BAY

CHART I
SURTRACE MAGNESIUM

Airborne Geochemical Survey



1 inch to 50 miles

N.T.S. Reference 42L/5, 42L/6
OGS Aeromagnetic Maps: P1588 P1589, P1593, P1594
OGS Geological Compilation Map: 2102

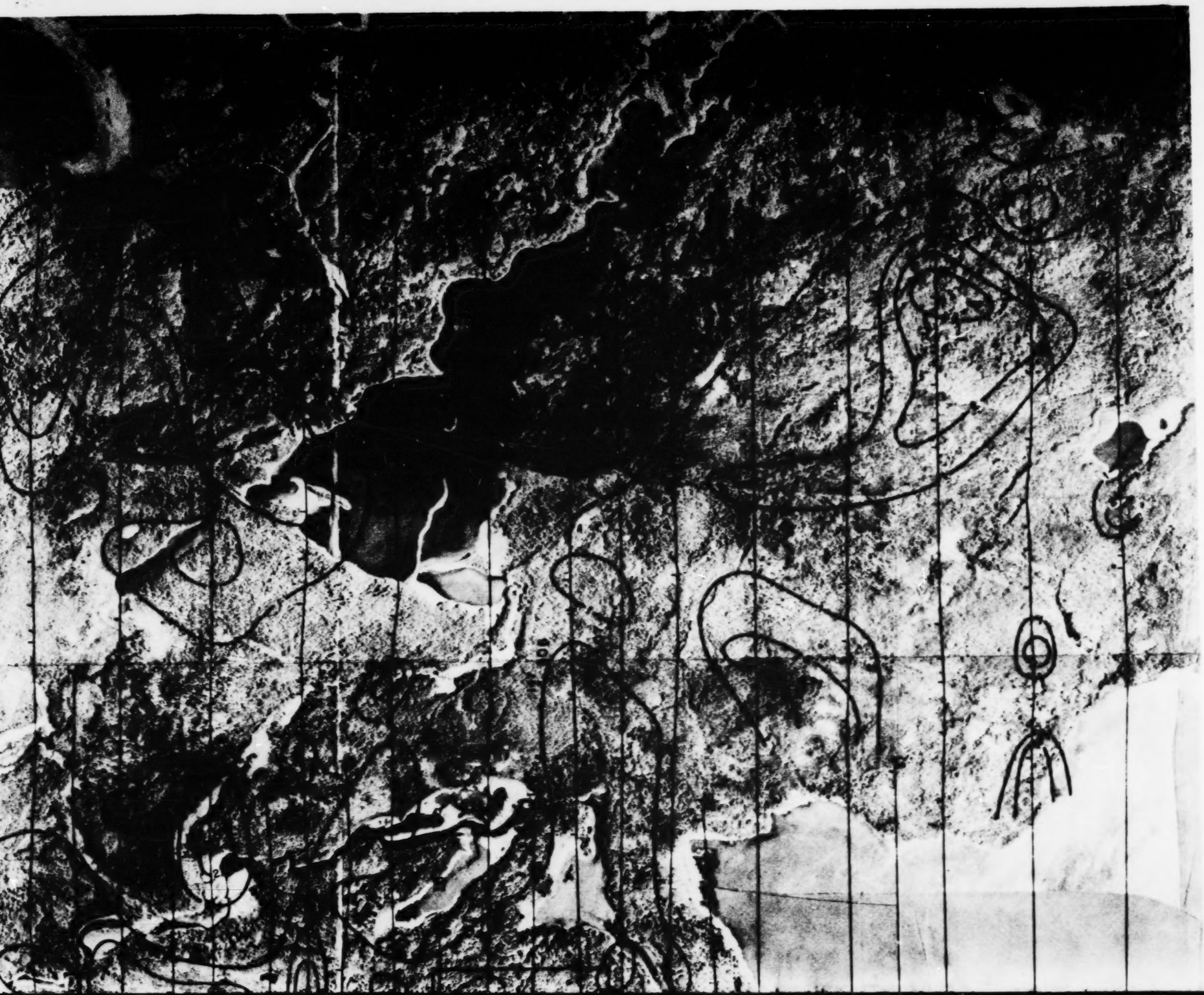
LEGEND

4 — Contours at standard deviation above the mean.

80 — Flight line with sample position and numbers.

808 — Ground sample stations and numbers.

Outline of detailed study area.



Ministry of Natural Resources
Ontario

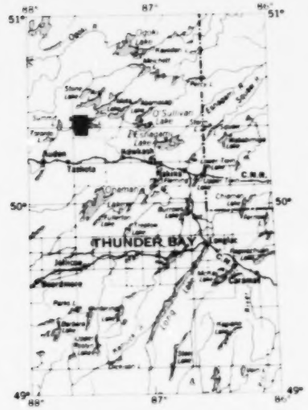
Ontario Geological Survey
Geophysical-Geochemical Series

MARSHALL LAKE

DISTRICT OF THUNDER BAY

CHART J
SURTRACE SILICON

Airborne Geochemical Survey



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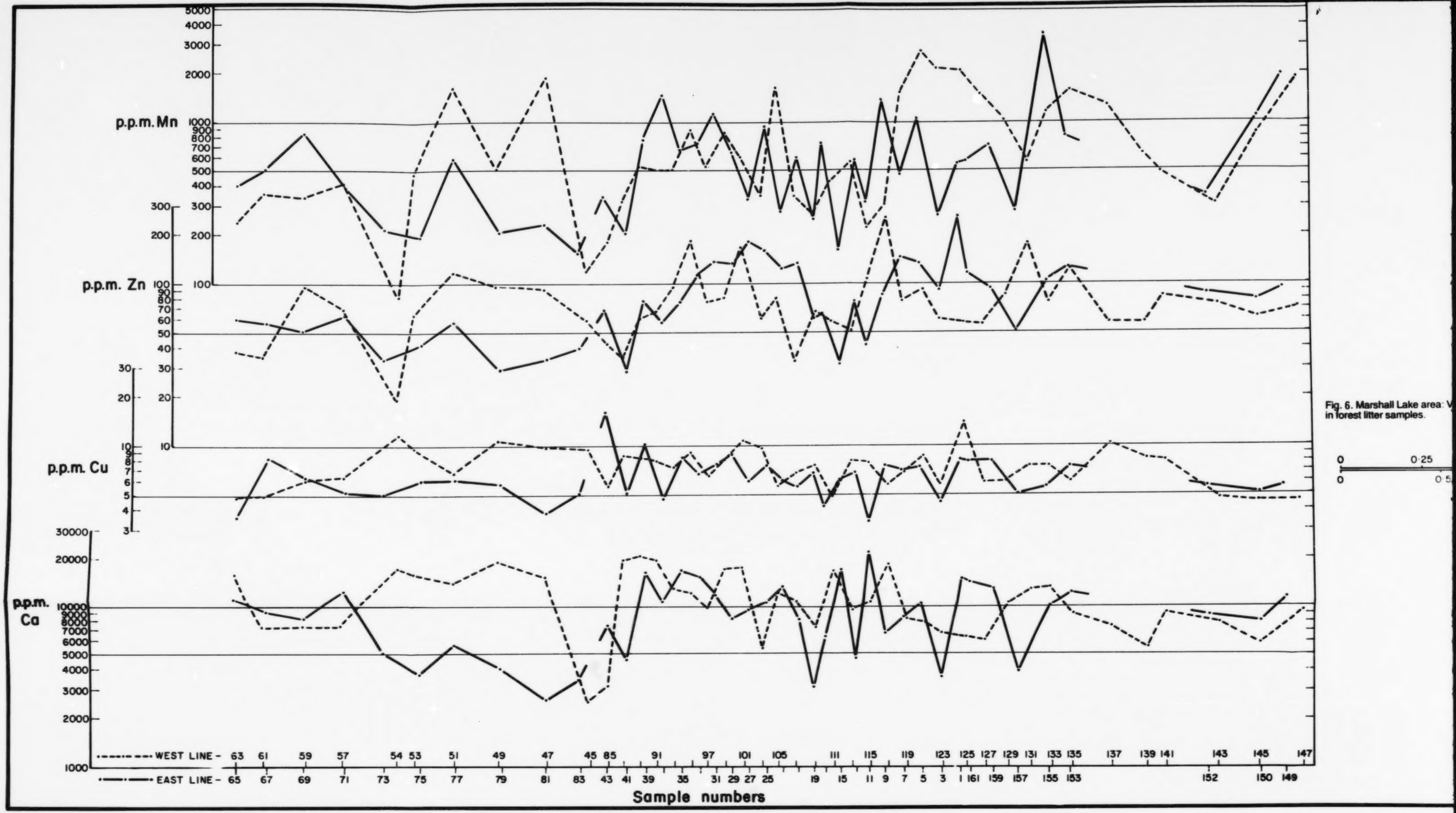


Fig. 6. Marshall Lake area: V
in forest litter samples.

0 0·25
0 0·5

SURTRACE Survey: Marathon and Marshall Lake areas.
Chart K
Figures 4, 5 and 6

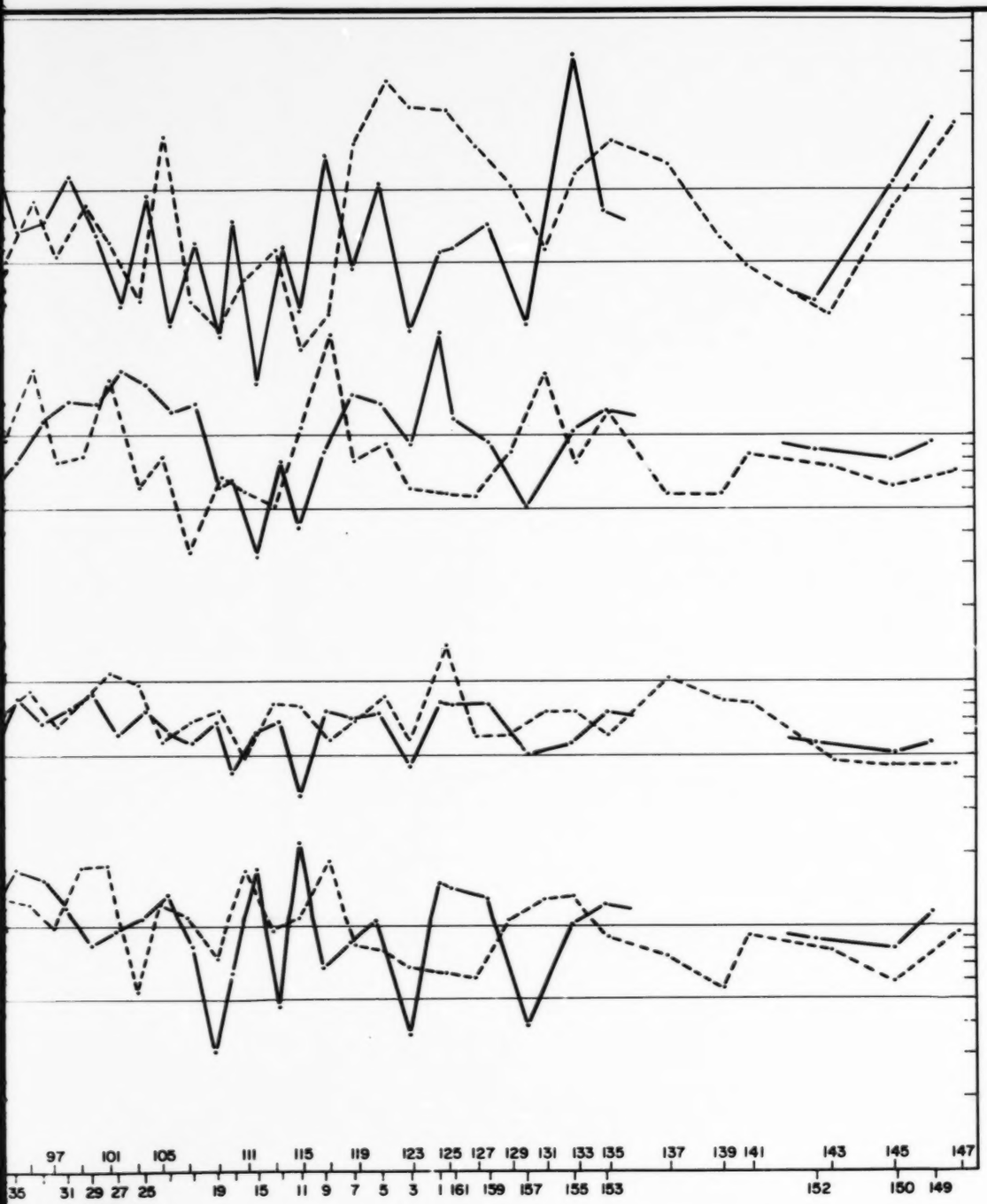
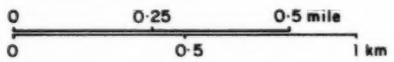


Fig. 6. Marshall Lake area: Variation of trace elements in forest litter samples.



STUDY AREA

105

95

numbers.

Outline of detailed study area.

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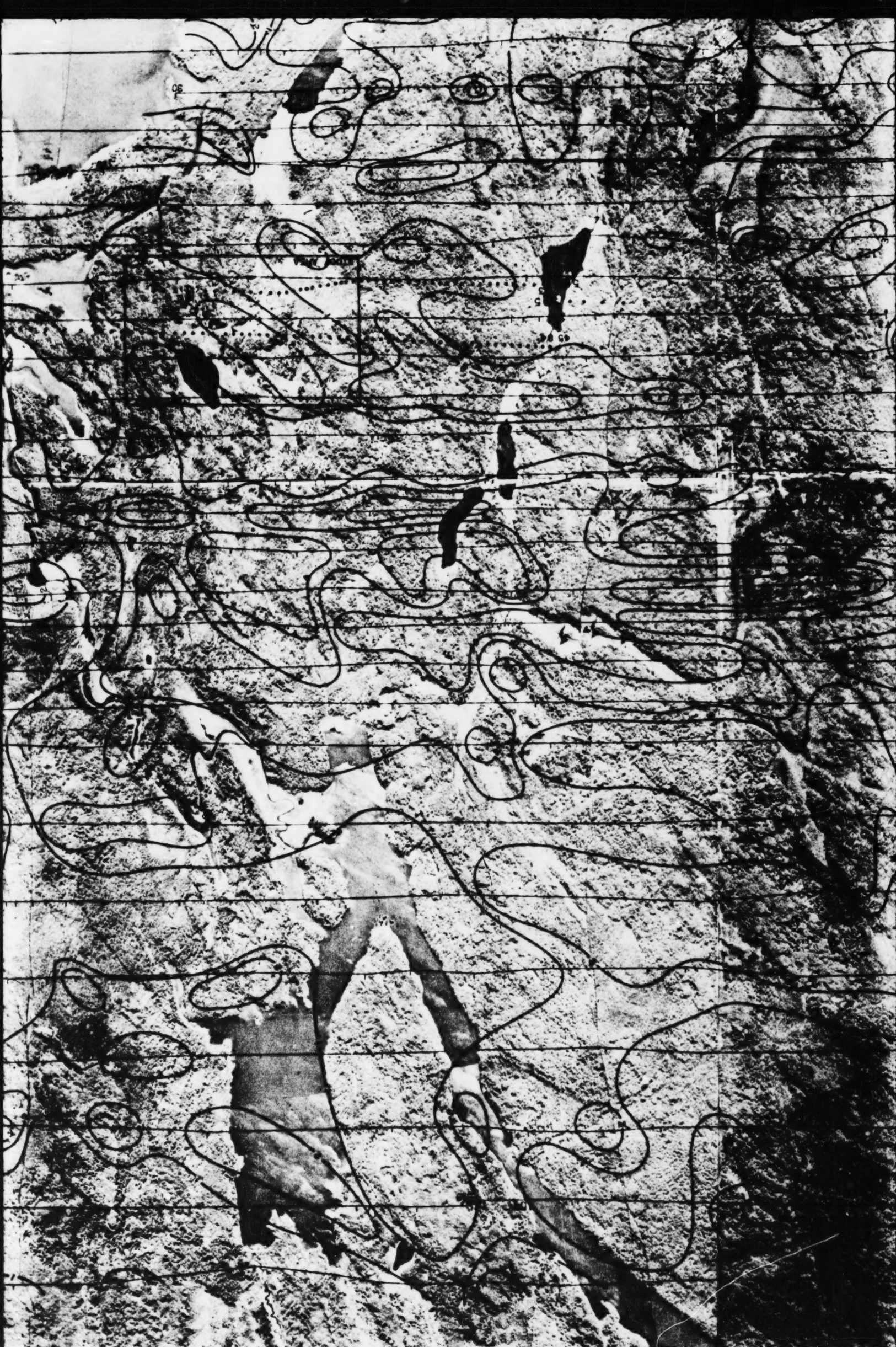

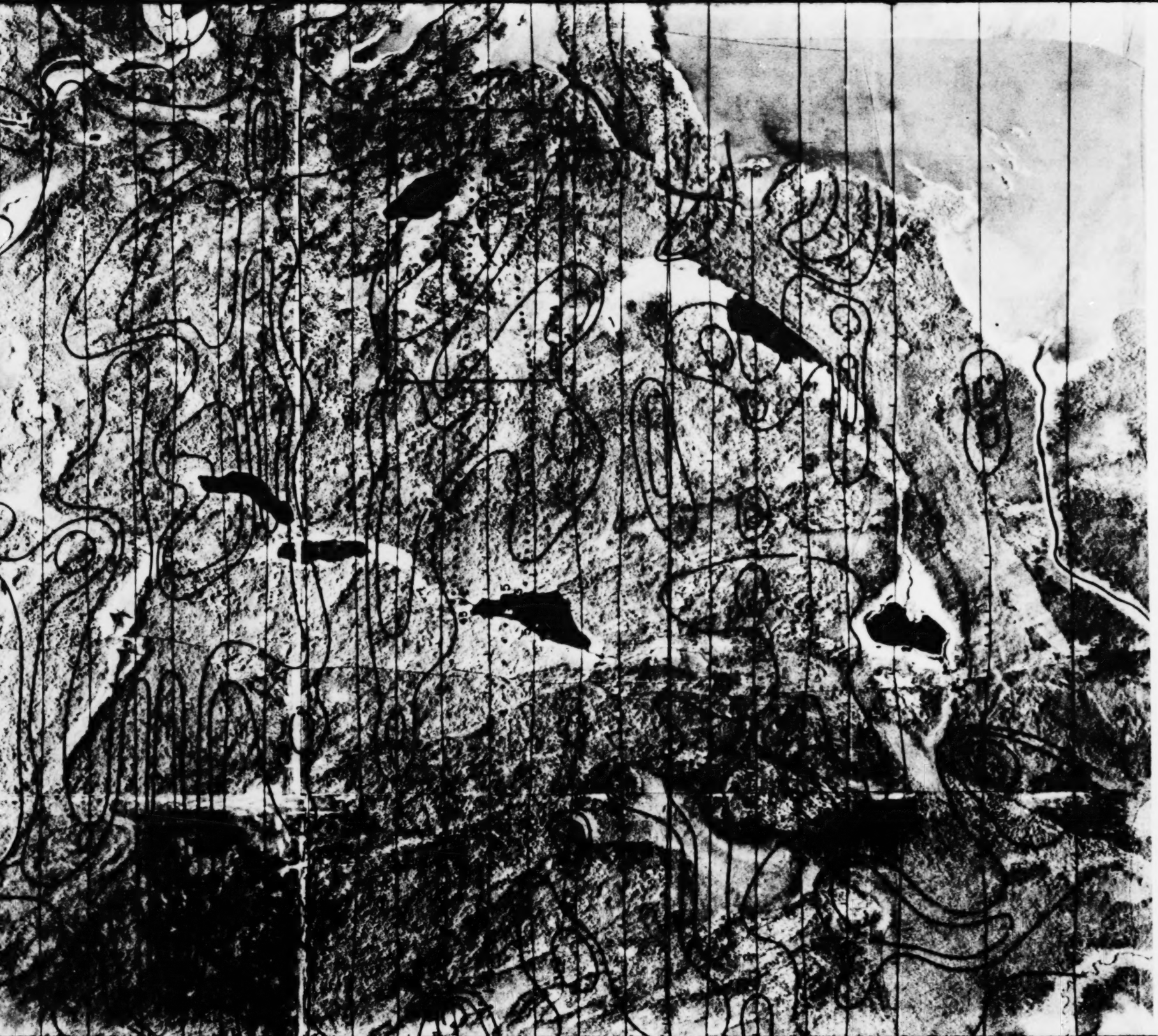

Ground sample stations and numbers.

Outline of detailed study area.

DESCRIPTIVE NOTES

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WEST LINE - 63 61 59 57 54 53 51 49 47 45 43 41 39 37 35 33 31 29 27 25 23 21 19 17 15 13 11 9 7 5 3 1 161 159 157 155 153 151 149 147 145 143

EAST LINE - 65 67 69 71 73 75 77 79 81 83 85 87 89 91 93 95 97 99 101 103 105 107 109 111 113 115 117 119 121 123 125 127 129 131 133 135 137 139 141 143 145 147

Sample numbers

V

Ti

Sr

Ni

Cu

Ca

437 438 440 445 450 455 460

Sample numbers

ample numbers

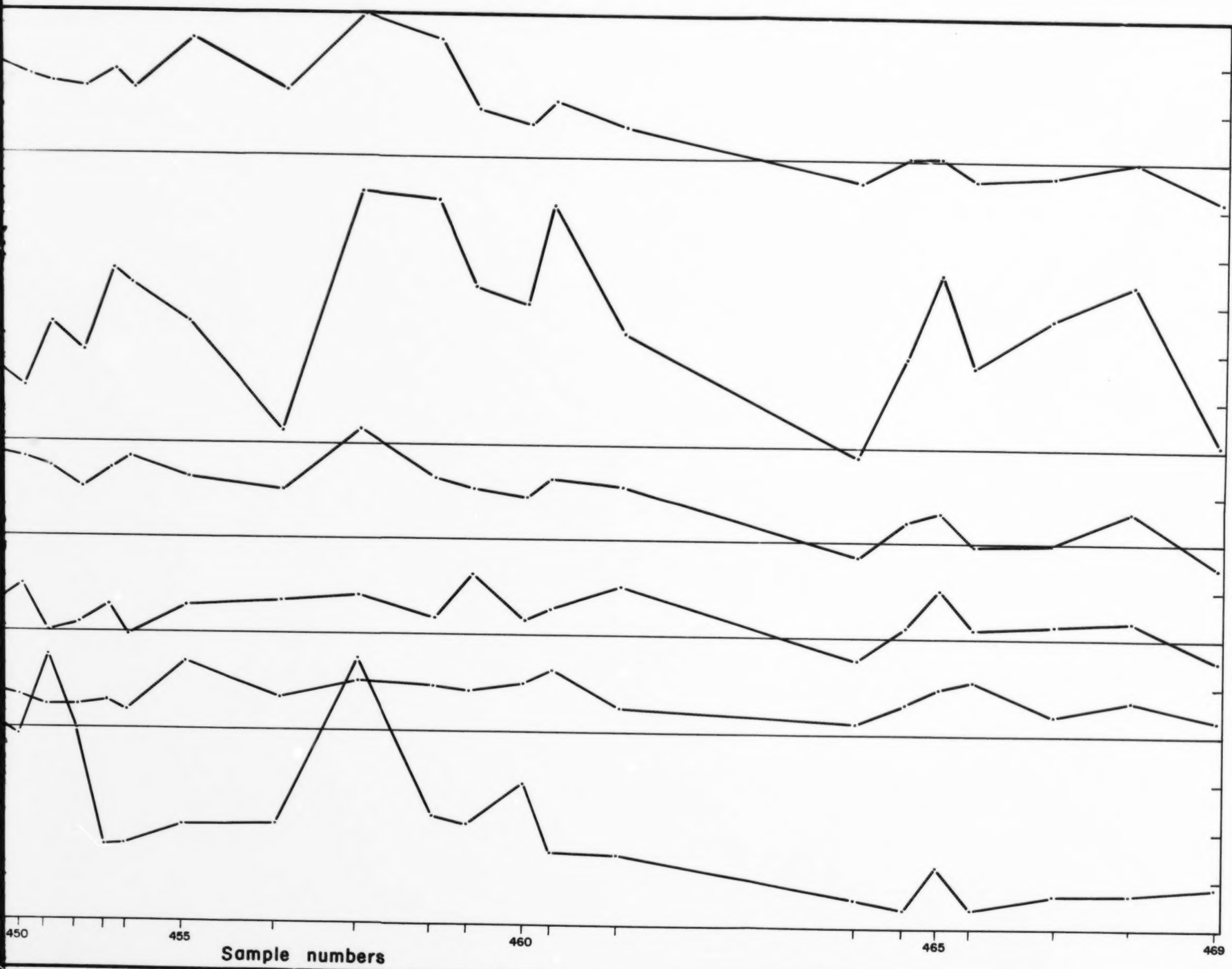
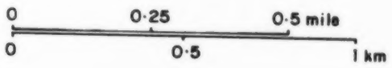


Fig. 5. Marathon area: Variation of trace elements in airborne SURTRACE samples.



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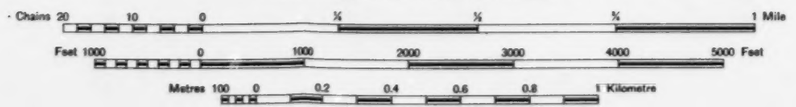
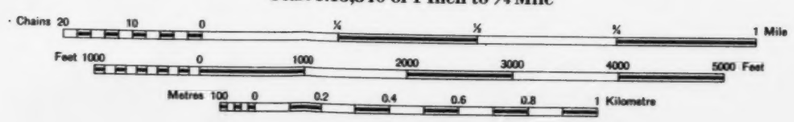
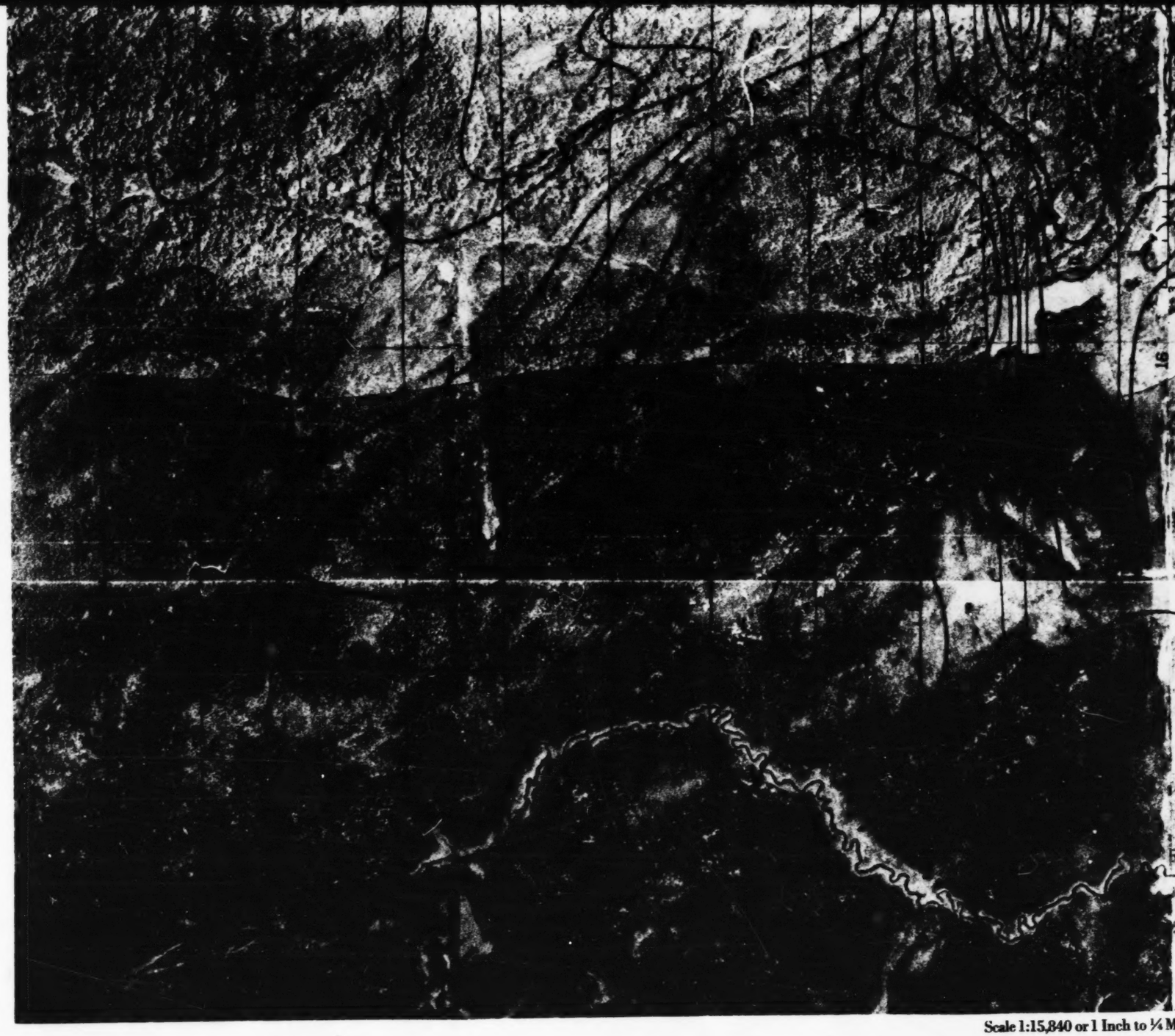
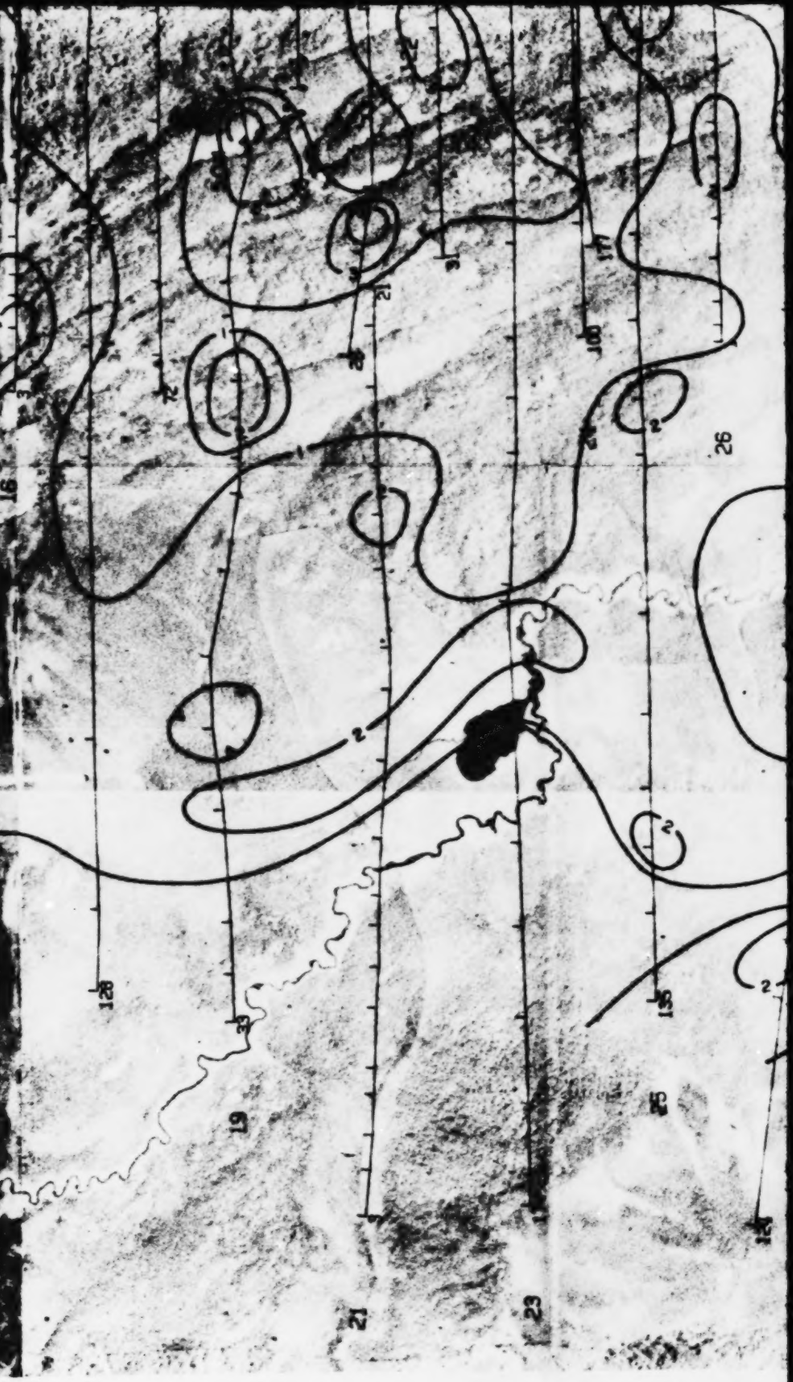


Scale 1:15,840 or 1 Inch to ¼ Mile



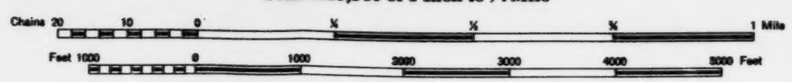
SMC 15018





Scale 1:15,840 or 1 Inch to ¼ Mile

Scale 1:15,840 or 1 Inch to ¼ Mile



Sample numbers

p.p.m. Ni

50
40
30
20
10
9
8
7
6
5
4
3
2

127

p.p.m. Sr

50
40
30
20
10
9
8
7
6
5
4

p.p.m. Cu

50
40
30
20
10
9
8
7
6
5

p.p.m. Ca

50000
40000
30000
20000
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000

79 77 75 73 71 69 67 65 63 61 59 55 51 47 43 39 35 31 27 21 15 9 5 3 1 81 85 87 91 95

Sample numbers

Sample numbers

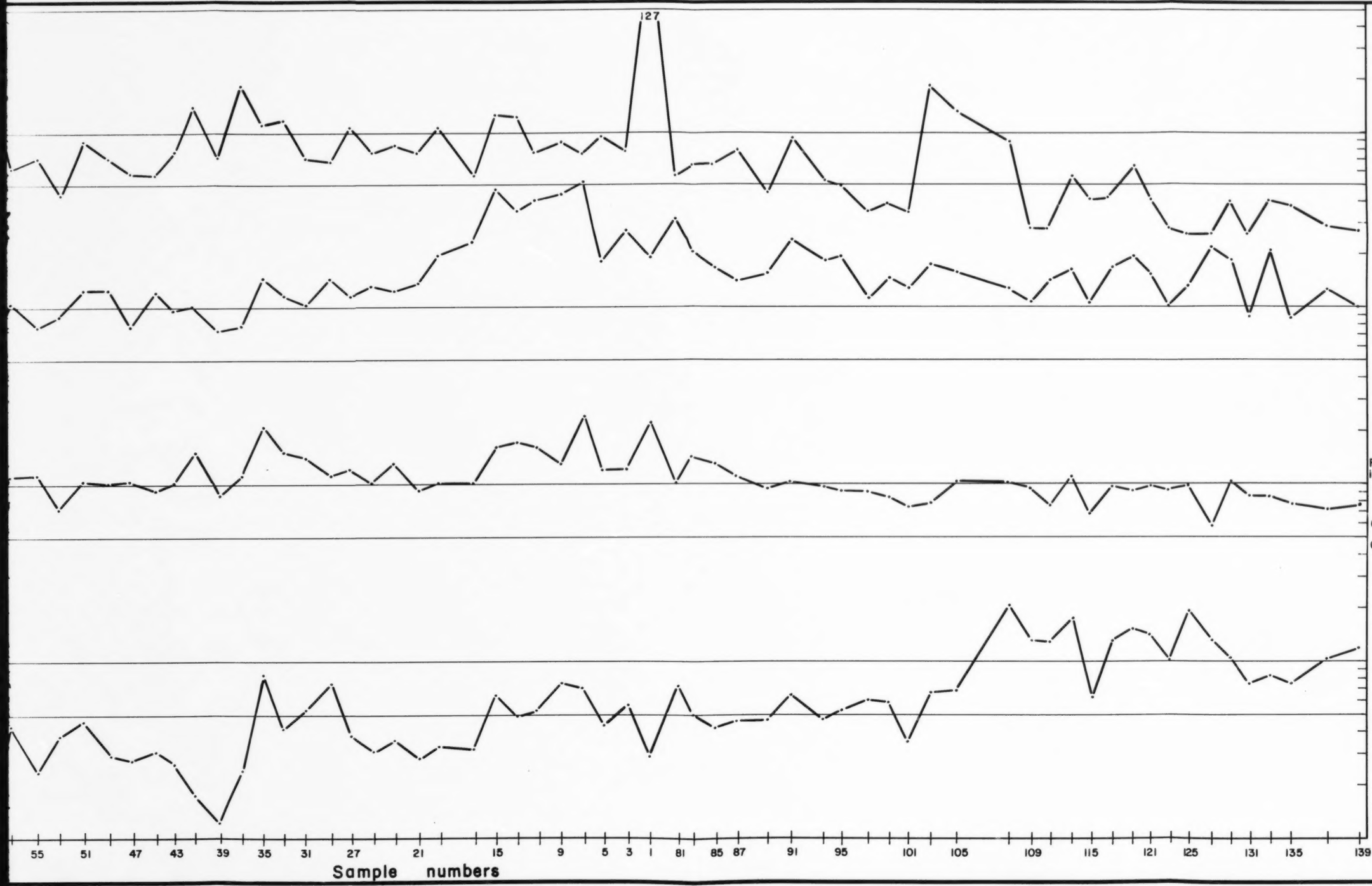


Fig. 4. Marathon area: Variation of trace elements in forest litter samples.

0 0·25 0·5 mile
0 0·5 1km